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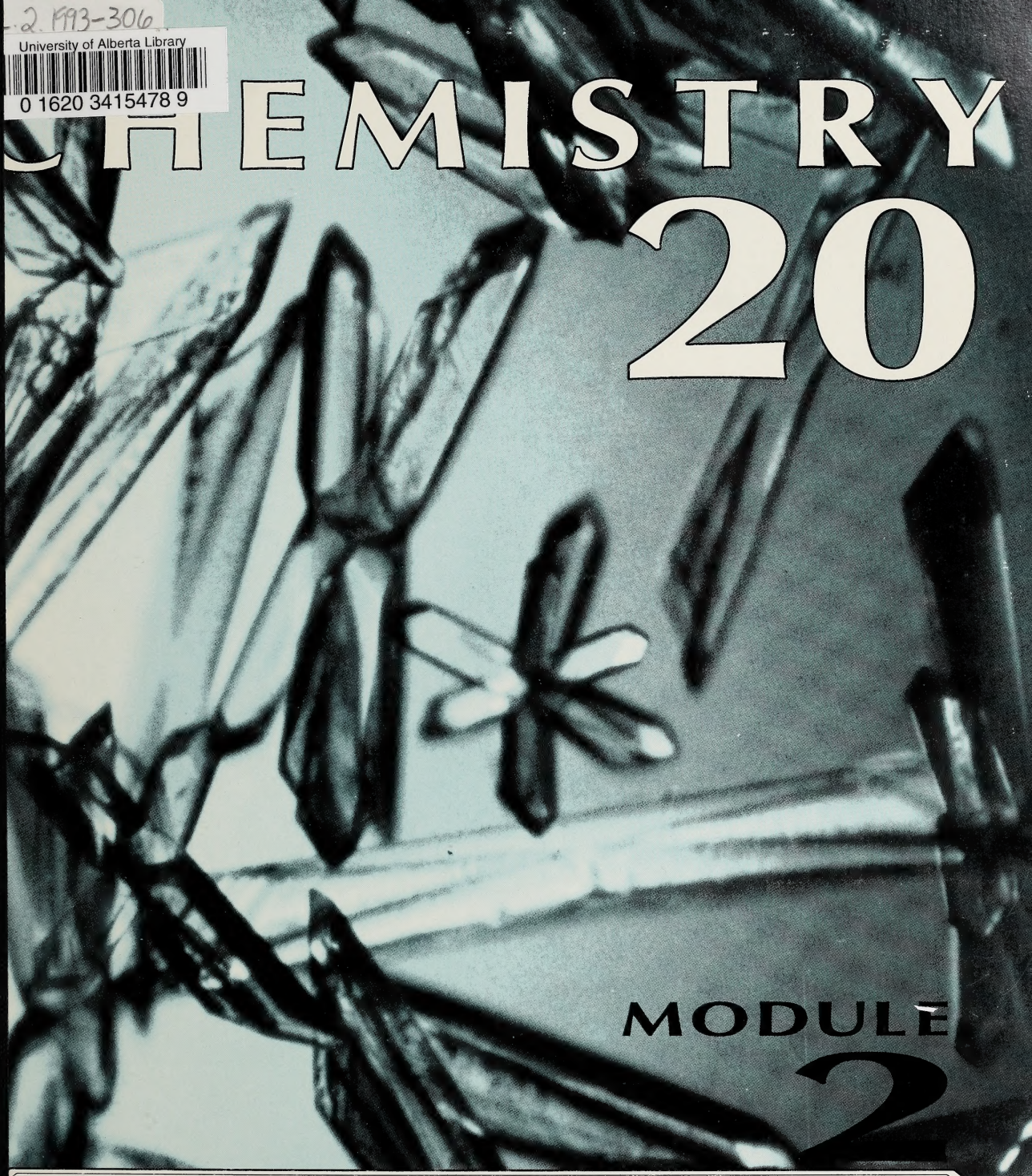

MODULE 2

ACIDS, BASES, AND GASES

Distance Learning

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Chemistry 20

Module 2

Acids, Bases, and Gases

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Chemistry 20
Student Module
Module 2
Acids, Bases, and Gases
Alberta Distance Learning Centre
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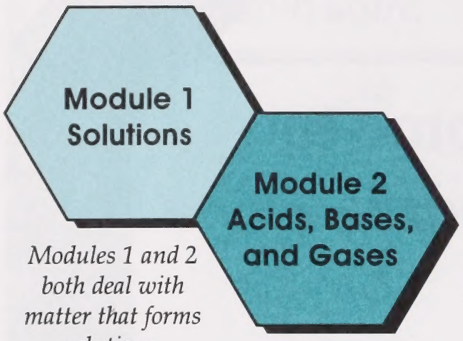
Welcome to Module 2!

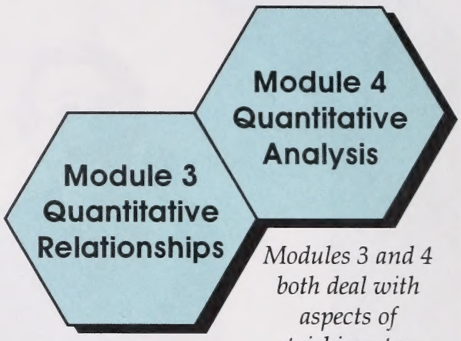
We hope you'll enjoy your study of *Acids, Bases, and Gases*. Remember, to make your learning a bit easier, several videocassettes and laser videodiscs are referred to throughout the modules. Your textbook *Nelson Chemistry* will also enhance your studies.

COURSE OVERVIEW

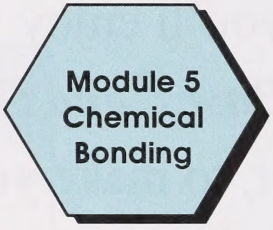
This course contains seven modules. The module you are working in is highlighted in deeper colour.

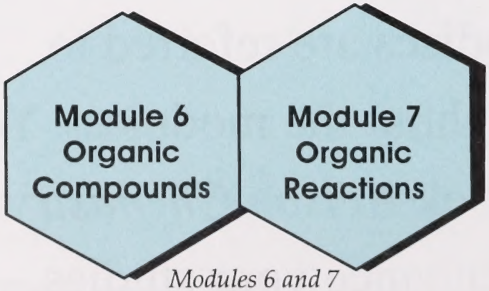


Modules 1 and 2 both deal with matter that forms solutions.



Modules 3 and 4 both deal with aspects of stoichiometry.





Modules 6 and 7 both deal with organic chemistry.

MODULE 2

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MODULE OVERVIEW

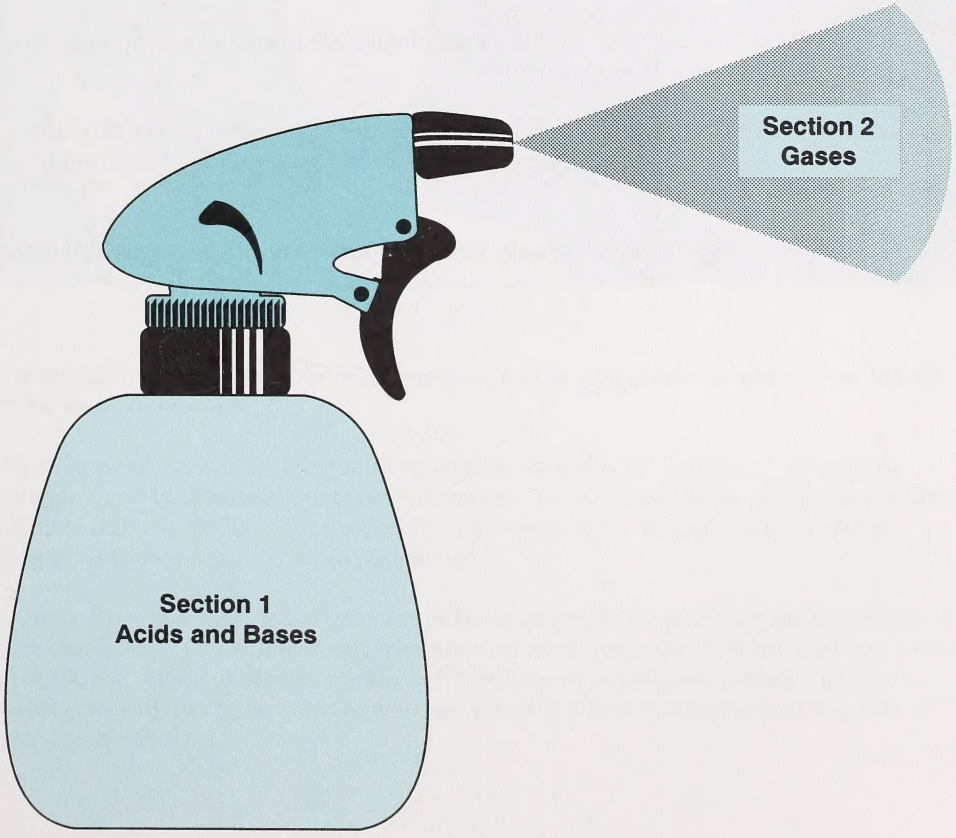
You have just eaten five oranges! You really like oranges, but all of a sudden, your stomach starts to hurt. Why is that? The citric acid in the oranges has upset your stomach. So you take a teaspoon of baking soda and … relief!

You have just experienced one aspect of acids and bases – neutralization. There is an abundance of acids and bases in the world. This module will explore the nature of these substances and look at the occurrence of acids and bases in your home and in industry.

You may have felt the need to burp when you took the baking soda. What caused this reaction? Other common types of substances around you are gases. You use gases to fill your tires. Gases allow balloons to soar. Gases are also used in spray cans.

In this module you will also study the various properties of gases and how they can be used in the world around you.

Module 2
Acids, Bases, and Gases



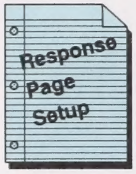
Evaluation

Your mark in this module will be determined by how well you complete the assignments at the end of each section. You must complete all assignments. In this module you are expected to complete two assignments. The mark distribution is as follows:

Section 1 Assignment	**40 marks**
Section 2 Assignment	**60 marks**
TOTAL	**100 marks**

When doing your assignments, work slowly and carefully. If you are having difficulties, go back and review the appropriate section.

Read all parts of your assignment carefully. Plan and do your rough work on your own paper. Revise and edit your responses; then set up your final copy for submission on your own paper. Lined looseleaf is recommended. Make sure your answers are neat and organized, with wide left margins and space for teacher comments after each assignment.



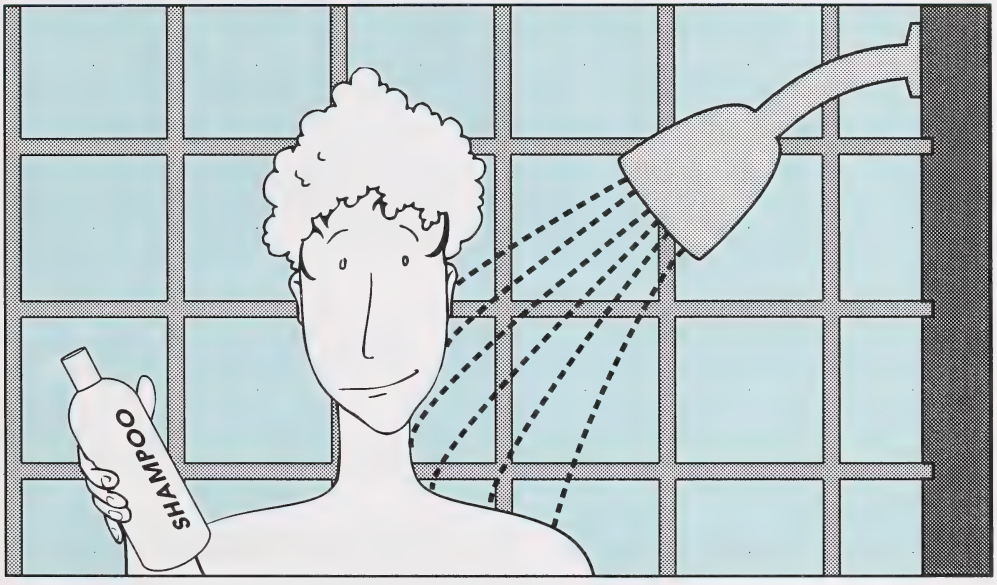
When you see this icon, ideas and details are provided to help you set up and organize your answer in a certain way.

Before submitting your responses, be sure to proofread them carefully to ensure they say what you want, that they are neat and clear, and that they are complete and missing no material.

You will be submitting **only** your **assignment response pages** for evaluation.

SECTION 1

Acids and Bases



You may know the pH of your hair shampoo, but do you know the pH of your blood? It's far more important!

The concept of pH is associated with substances called acids and bases. People, in general, know very little about these substances. Even though acids and bases are often mentioned in the media, their properties aren't discussed. Are all acids and bases dangerous to you and to your environment?

In this section you will look at answers to these questions by studying the properties of acids and bases. You will find out why you can wash your eyes in boric acid and suffer no ill effects. You will discover many acids and bases in your own home that are very useful. Not only will you learn how to calculate the pH of your shampoo, but also of your orange juice.

ACTIVITY 1

What Are Acids and Bases?

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In Science 10 and in Module 1 of this course, you learned about some properties of acids and bases. You may wish to review this material.

empirical definition – a definition based on observable properties

The properties you reviewed form **empirical definitions** of acids and bases. The term *operational* is often substituted for the term *empirical*, but in this course you will use the term *empirical*.

1. Create a chart and list two properties for each of acids and bases.

Acids	Bases

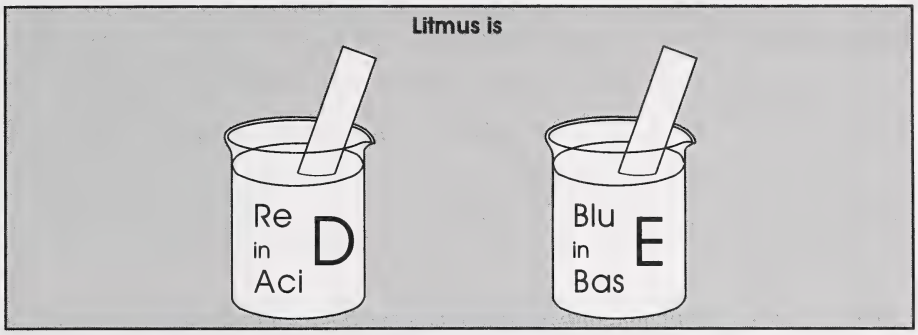
Check your answers by turning to the Appendix, Section 1: Activity 1.

Nelson CHEMISTRY

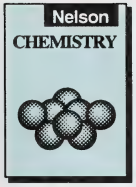
Suppose that you have three unlabelled solutions in front of you and they are all identical. You know that you have an acid, a base, and a neutral solution. How can you identify each solution? You could test the solutions for conductivity, but that wouldn't help because all three solutions contain electrolytes. Read the section Acidic, Basic, and Neutral Solutions on page 114 of your textbook to see how you can solve this dilemma.

2. a. What kind of a test would you perform in order to identify each of the three solutions as being either acidic, basic, or neutral?

   b. What would the result of the test be for each solution?



Check your answers by turning to the Appendix, Section 1: Activity 1.



In the preceding question you identified some unique properties of acids and bases. In Science 10 you learned that acids also have unique naming systems. For a review of these naming systems, read the section on Acid Nomenclature in *Nelson Chemistry* on pages 118 and 119.

3. Answer questions 5 and 6 on page 120 of your text.

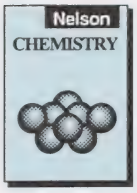
Check your answers by turning to the Appendix, Section 1: Activity 1.

Since bases are ionic compounds, they do not have a unique naming system. However, many bases do have common characteristics.

4. Identify two common characteristics of the following bases: NaOH (sodium hydroxide), $Ca(OH)_2$ (calcium hydroxide), and $Al(OH)_3$ (aluminum hydroxide).

Check your answers by turning to the Appendix, Section 1: Activity 1.

As you have discovered, the bases in the previous question all contain hydroxide ions. This characteristic was also observed by Arrhenius in the late 1800s.



Arrhenius developed a theory on both acids and bases from his observations. To understand the theory that he proposed, read Section 5.2 Understanding Solutions on pages 115-117 in *Nelson Chemistry*. If you are interested in human history, read the biography and look at the photograph of Arrhenius on page 116.

5. What was Arrhenius's definition of an acid?

6. What was Arrhenius's definition of a base?

7. To review what happens to acidic and basic substances in solution, identify which of the two processes, ionization or dissociation, each of the following substances undergoes in solution.

   a. HI

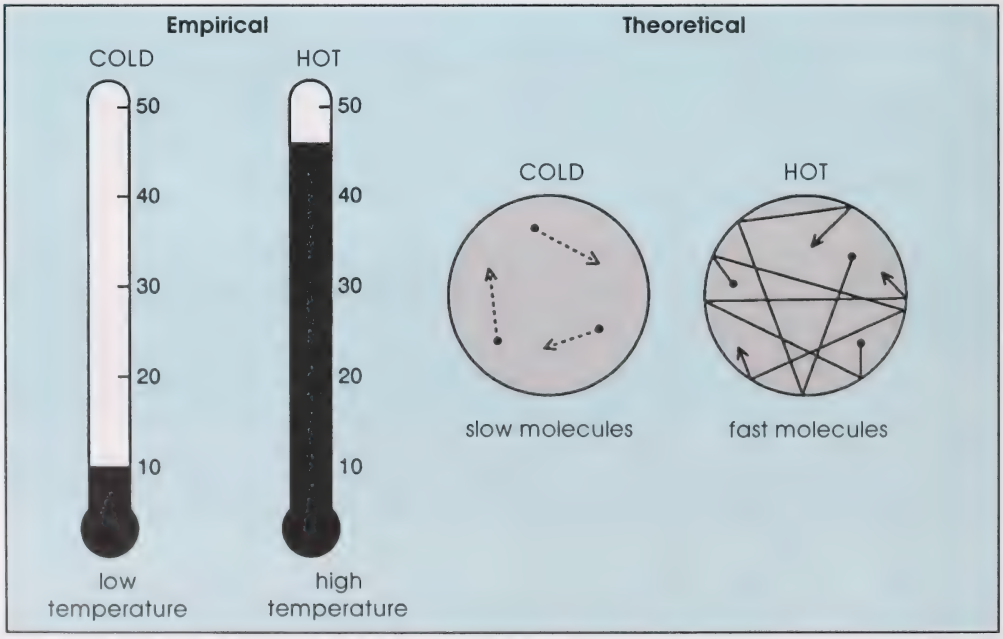
   b. $Ca(OH)_2$

Check your answers by turning to the Appendix, Section 1: Activity 1.

theoretical definition – a definition that explains why something behaves the way it does

Earlier in this activity you explored the empirical definitions of acids and bases. Arrhenius's definitions of an acid and a base are theoretical definitions.

Theoretical definitions not only explain the properties of acids and bases, but they also allow you to predict if something is an acid or a base simply by looking at its chemical formula. The term *conceptual* may often be substituted for the term *theoretical*. In this course you will use the term *theoretical*.



Refer to Table 5.1 on page 117 of your textbook to complete the following two questions.

8. Complete the table.

Characteristic	Acidic, Basic, or Neutral Substance	Empirical or Theoretical Definition
turns litmus blue		
contains many OH^-		
neutralizes acids		
tastes sour		
no affect on litmus		

9. Table 5.1 mentions that neutral solutions can contain electrolytes or non-electrolytes (as you learned in Module 1). What is the chemical nature of the solute that would be dissolved in each solution?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Table 5.1 on page 117 of your textbook states that acids and bases neutralize each other. What is **neutralization**? Why does calamine lotion (a weak base) make a bee sting (a weak acid) feel better? Or why do wasp stings (a weak base) feel better when treated with vinegar (a weak acid)?

neutralization – a reaction that eliminates the active properties of an acid or base

Now that you have learned the theoretical definitions of acids and bases, you are ready to learn why these substances have a neutralizing effect on each other.

10. Complete the following double replacement reaction:

$$HCl_{(aq)} + KOH_{(aq)} \rightarrow$$

Check your answers by turning to the Appendix, Section 1: Activity 1.

The preceding reaction shows that the products of a strong acid-base reaction are a neutral ionic compound and water.

Arrhenius believed that the aqueous hydrogen ions were responsible for the properties of acids and that the aqueous hydroxide ions determined basic properties. In neutralization, when the $H^+_{(aq)}$ and the $OH^-_{(aq)}$ combine to form $H_2O_{(l)}$, the distinctive acidic and basic properties are eliminated.

$$\underset{\text{Acid}}{H^+_{(aq)}} + \underset{\text{Base}}{OH^-_{(aq)}} \rightarrow \underset{\text{Neutral}}{H_2O_{(l)}}$$

11. Write balanced equations for the following neutralization reactions.

    a. $HNO_{3(aq)} + CsOH_{(aq)} \rightarrow$

    b. $H_2SO_{4(aq)} + NH_4OH_{(aq)} \rightarrow$

    c. $Ca(OH)_{2(aq)} + HBr_{(aq)} \rightarrow$

12. Certain commercial stomach antacids contain substances like aluminum hydroxide and magnesium hydroxide. Show how these chemicals theoretically neutralize stomach acid (HCl).

13. In a preceding question you saw a neutralization reaction with $HCl_{(aq)}$ and $KOH_{(aq)}$. If $H^+_{(aq)}$ and $OH^-_{(aq)}$ are the active participants from these substances, what happens to the other ions?

Check your answers by turning to the Appendix, Section 1: Activity 1.

To confirm your understanding of acidic, basic, and neutral substances, perform Investigation 5.1: Chemical Analysis on page 115 of your textbook.

Investigation 5.1: Chemical Analysis

Science Skills

- [x] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Carefully follow the directions given for this investigation. Pay special attention to the required components, safety aspects, and applied science skills.

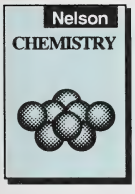
In this investigation you will deal with the empirical and theoretical definitions of acidic, basic, and neutral solutions.

Guidelines

- Do not handle any of the solids with your hands. Calcium hydroxide is corrosive.
- To make solutions of the solutes A-D, dissolve 1 mL (a pill-sized piece or 1/4 tsp.) of each unknown in 10 mL of $H_2O_{(l)}$.

14. Write a brief description of your design.
15. Make a list of your materials.
16. List the steps in your procedure. Don't forget to include the amounts of the materials used.
17. Record your evidence in a data table.
18. As the analysis, identify each solute. Give a reason for each choice.

Check your answers by turning to the Appendix, Section 1: Activity 1.



19. As a review of the concepts you have learned, complete questions 6, 15 (a, b, c), and 20 on page 140 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 1.

You have added the theoretical definitions of acids and bases to the empirical definitions you learned in Science 10. In the next activity you will see that acids and bases are more useful and more common than you may have thought. You will also see that some acids are more dangerous than others and need to be handled carefully.

ACTIVITY 2

Acids and Bases in Everyday Life

Acids and bases are not only found in the lab. Did you know that many acids and bases can be found in your home? What kinds of solutions are acids and bases, and what do you use them for? To answer these questions, perform the following investigation.

Investigation: Common Household Acids and Bases

Science Skills

- [x] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

In this investigation you will be testing at least ten common household substances with litmus paper to see if they are acids or bases.

Carefully follow the directions of this investigation. Pay special attention to the required components, safety aspects, and applied science skills.

Guidelines

Caution

- Do not allow drain cleaner, oven cleaner, or trisodium phosphate to touch your skin.
- You may choose to test any of these common household items: vinegar, garden lime, antacid tablets, baking powder, window cleaner, soft drinks, milk, shampoo, coffee, drain cleaner, tap water, lemon juice, ketchup, pickles, boric acid (borax), trisodium phosphate, dish detergent, ASA tablets, vitamin C, oven cleaner, cream of tartar, and bleach.
- Any solids that need to be tested must be dissolved in solution first. Do this by adding 1 mL (1/4 tsp. or a pea-sized amount) of any solid to 10 mL of water.

1. Write a brief description of your design.
2. List all the items you will test and any other materials you will need.
3. List the steps in your procedure.

4. Record your evidence in a data table. In addition to noting the effect each substance has on litmus paper, state whether the substance is a cleaner or if it is edible.

As your analysis, summarize the results by answering these questions based on information in your data table.

5. Determine which substances are acids, bases, or neutral substances and list them accordingly.

Acids	Bases	Neutral Substances

6. In general, what types of substances are acids, and what types of substances are bases?

As you have seen, many acids and bases are present in your home. Acids and bases are also very important in industrial processes.

7. Name any acids and bases you know of that may be used in industry.

Check your answers by turning to the Appendix, Section 1: Activity 2.

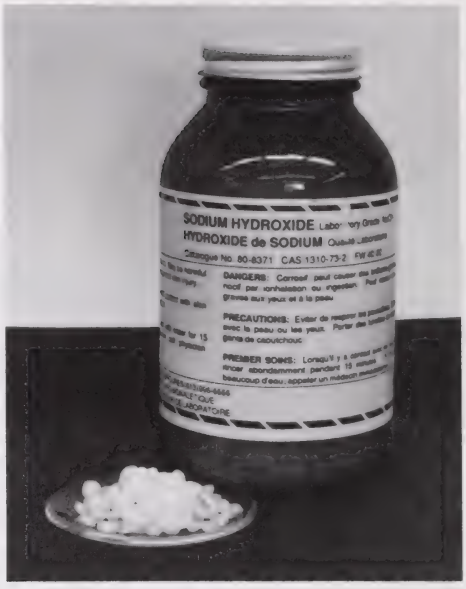
You may have heard of lime which is used to make cement. It is an important industrial base for use in the production of glass. You have probably also heard of hydrochloric acid. It is used in the industrial production of rubber and pharmaceuticals. Nitric acid is used for explosives; hydrofluoric acid is used for etching glass. Many acids and bases are used industrially, but here you will concentrate on one acid and one base – both of which are produced in Alberta!

Petroleum Communication Foundation

In the preceding picture the huge blocks of yellow solid shown on the left are a common sight in Alberta. Do you know what the substance is in the blocks? It is sulphur, and much of it goes into the production of sulphuric acid, H_2SO_4, a frequently used chemical in industry.

One of the most heavily used industrial bases is NaOH. Both NaOH and H_2SO_4 are produced at Fort Saskatchewan in Alberta. Both are used within the province in various technological processes.

Figure 2.1 provides some information on NaOH and H_2SO_4. Read over the information and answer the questions that follow.



Substance	H_2SO_4	NaOH
Common Name	oil of vitriol	caustic soda
Productive Process	contact process: $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$ $SO_{2(g)} + O_{2(g)} \rightarrow SO_{3(g)}$ $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$	electrolysis of brine (salt water): $NaCl_{(aq)} \rightarrow NaOH_{(aq)} + Cl_{2(g)}$ The H_2O in which the NaCl is dissolved provides the OH^- ions in the NaOH product.
Uses in Industry	fertilizers, paints, soapless detergents, dyes, plastic, car batteries, explosives, pesticides, pharmaceuticals, metallurgy, petroleum refining	soaps, rayon, dyes, paper, pharmaceuticals, rubber, bleaches, aluminum production, petroleum refining, metallurgy, textiles

FIGURE 2.1: Production and Uses of H_2SO_4 and NaOH

8. How does the information in the chart support the claim that NaOH and H_2SO_4 are industrially important?

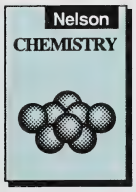
9. In which industries are both NaOH and H_2SO_4 involved?

10. a. When you make sodium hydroxide, what other product is formed that must then be removed?

    b. What uses does this second product have in everyday life?

11. Why is Alberta a good place to have an H_2SO_4-producing plant?

Check your answers by turning to the Appendix, Section 1: Activity 2.



Sulphuric acid and sodium hydroxide are very useful chemicals, but they are also very dangerous! However, you have also seen a large number of acids and bases used in your home that are not very dangerous. You may have used the terms *strong* and *weak* to describe these acids and bases before, but do you really know what the terms mean? To discover how these terms relate to acids and bases, read Substances in Water on page 118 of your textbook, including Table 5.2, and then answer the following questions.

12. Arrhenius said that acids increase the amount of $H^+_{(aq)}$ in a solution. In terms of Arrhenius's definition, how do strong acids differ from weak acids? (Refer back to pages 116 and 117 of your textbook to read about Arrhenius.)

13. Boric acid can be used to clean your eyes. Do you think it is a strong or a weak acid?

14. Identify the following acids as either weak or strong. Assume aqueous states.

Acid	Strength
$HClO_2$	
$HClO_4$	
C_6H_5COOH	
H_3PO_4	

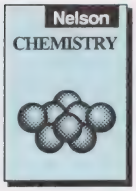
15. In the following acid solutions, list the major entities present in the water environment.

a. $HCl_{(aq)}$ b. $HNO_{2(aq)}$ c. $CH_3COOH_{(aq)}$

You have just seen that contact with some acids is possible because many acids are weaker and don't ionize much. It may surprise you to know, however, that you are in close contact with a strong acid all the time. You have $HCl_{(aq)}$ in your stomach! Why doesn't it harm you? Think back to Module 1 where you learned about solutions and concentration.

16. If a solution has very few moles of solute per litre, what kind of solution is it?

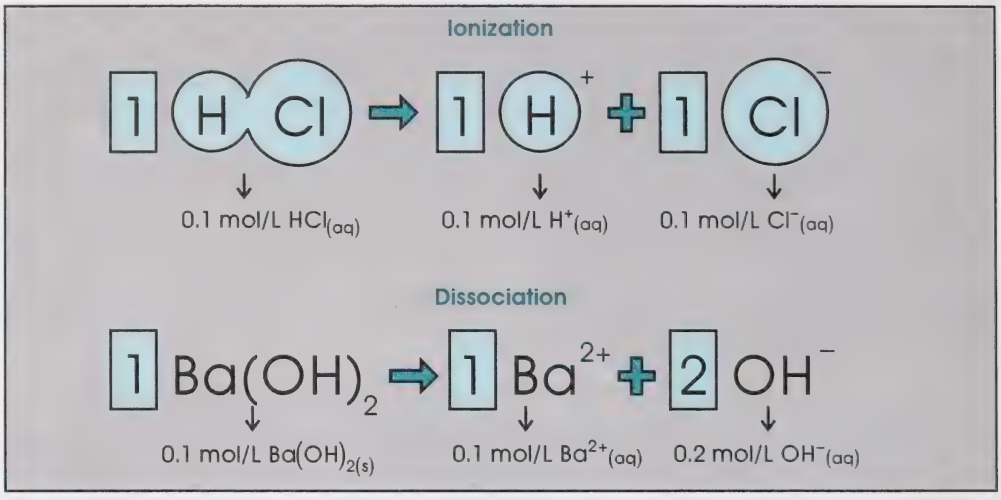
Check your answers by turning to the Appendix, Section 1: Activity 2.



Stomach contents are an example of a strong acid solution that isn't very concentrated. Another example is nitric acid, $HNO_{3(aq)}$. Even though $HNO_{3(aq)}$ can be quite corrosive and dangerous, a dilute nitric acid solution can be fairly harmless. To really know how dangerous an acid is, you need to be able to calculate the concentration of its hydrogen ions. The same is true for a strong base and its hydroxide ions. To see how this is done, go to page 129 of your textbook and read the section Concentration of Ions.

ionization – the process whereby a molecular compound forms ions

dissociation – the process whereby an ionic compound separates into its ions



17. Write either dissociation or ionization equations for solutions of the following acids or bases. Identify the initial state of the acid as aqueous$_{(aq)}$ and the initial state of the base as solid$_{(s)}$.

    a. nitric acid

    b. strontium hydroxide

18. Calculate the concentration of hydroxide ions in these bases.

    a. 0.60 mol/L $Ca(OH)_{2(aq)}$

    b. 0.52 mol/L $Al(OH)_{3(aq)}$

    c. 0.86 mol/L $NaOH_{(aq)}$

    d. Which of these solutions is most basic?

19. Match the following acid solutions to the appropriate concentrations of $H^+_{(aq)}$ ions. (**Note:** > means greater than; < means less than.)

    a. 0.10 mol/L $HCl_{(aq)}$

    b. 0.10 mol/L $CH_3COOH_{(aq)}$

    c. 0.10 mol/L $H_2SO_{4(aq)}$

    i. > 0.10 mol/L $H^+_{(aq)}$

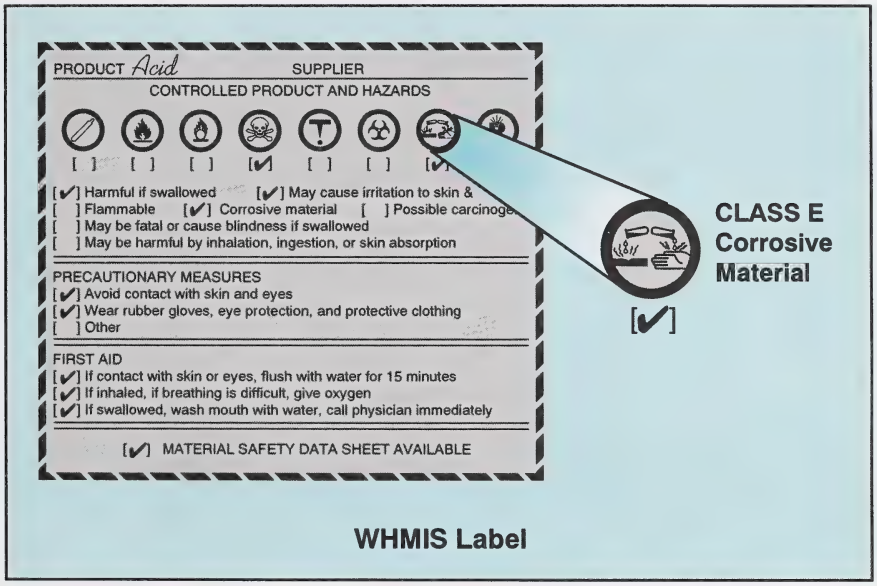
    ii. = 0.10 mol/L $H^+_{(aq)}$

    iii. < 0.10 mol/L $H^+_{(aq)}$

20. In the preceding questions, why were you not asked to calculate the $H^+_{(aq)}$ concentration of a weak acid solution?

Check your answers by turning to the Appendix, Section 1: Activity 2.

So far, you can calculate the concentrations of $H^+_{(aq)}$ ions in a strong acid and $OH^-_{(aq)}$ in a strong base, but not $H^+_{(aq)}$ ions in a weak acid. What about a weak base? All vital hydroxides are strong bases, and you will have to wait until Chemistry 30 to learn about calculations involving weak acids and bases.


PRODUCT Acid
SUPPLIER
CONTROLLED PRODUCT AND HAZARDS
[ ] [ ] [ ] [✔] [ ] [ ] [✔]
[✔] Harmful if swallowed [✔] May cause irritation to skin &
[ ] Flammable [✔] Corrosive material [ ] Possible carcinoge
[ ] May be fatal or cause blindness if swallowed
[ ] May be harmful by inhalation, ingestion, or skin absorption
PRECAUTIONARY MEASURES
[✔] Avoid contact with skin and eyes
[✔] Wear rubber gloves, eye protection, and protective clothing
[ ] Other
FIRST AID
[✔] If contact with skin or eyes, flush with water for 15 minutes
[✔] If inhaled, if breathing is difficult, give oxygen
[✔] If swallowed, wash mouth with water, call physician immediately
[✔] MATERIAL SAFETY DATA SHEET AVAILABLE
CLASS E
Corrosive
Material
[✔]
WHMIS Label

Acids and bases are dangerous when there is a combination of high concentration and a strong acid or base. Can you think of any instances of this combination in your home? Two examples of dangerous home products are drain cleaner (containing NaOH) and commercially available muriatic acid (containing HCl). If you, your friends, or your family are handling these, do so with care.

To become more aware of how acids and bases can be safely handled, complete the next question.

21. The following is a list of practices for the safe handling of acids and bases, some emergency procedures for cleaning up spills, and some steps dealing with actual contact with strong acids and bases. The list is all mixed up. Make a chart with two headings – Safe Practices and Emergency Procedures. Read each statement carefully and place it under the appropriate heading.

- Wear goggles and an apron.
- Keep chemicals away from the lab book or the edge of the table.
- If you spill an acid or a base, notify those around you.
- Use gloves when cleaning up a large spill.
- Know the location of the nearest safety equipment.
- Clean up spills immediately.
- Do only what the lab procedure says.
- Use acid or base neutralizer on an acid or base spill.
- When you get acid on you, flush the area with water.
- When acids are diluted, always add the acid to the water to prevent a large heat build-up.
- Treat an acid spill on your skin immediately.
- Use only small amounts of acid.
- Do not wear contact lenses in the lab.

Check your answers by turning to the Appendix, Section 1: Activity 2.

You have examined the composition of acids and bases, what makes acid and base solutions dangerous, and how to deal with them safely. In Activity 3 you will learn some new ways of expressing and determining the acidic or basic strength of a solution.

ACTIVITY 3

H^+ and pH

Your shampoo is not the only solution that has a pH. All solutions have one. Even soil has a pH value. What is pH? Can it be changed? Farmers measure the pH of their fields and may decide to change it before they seed. Some plants, like spruce trees, like to grow in a low pH soil, whereas others, like cabbage, prefer a soil with a higher pH.

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To find out what **pH** really is, go to your textbook and read the section called Communicating Hydrogen Ion Concentration from page 129 up to and including page 131. Omit the section on Biomagnification.

pH – a logarithmic scale that indicates how acidic or basic a solution is;

$$pH = -\left(\log\left[H^{+}_{(aq)}\right]\right)$$

1. Express the concentration of hydrogen ions $\left(\left[H^{+}_{(aq)}\right]\right)$ in each of the following solutions.

   a. acidic solution

   b. neutral solution

   c. basic solution

2. a. What is the definition of pH?

   b. Of what is pH a measure?

It is probably no surprise to you that acidic solutions contain $H^{+}_{(aq)}$ ions, but it may surprise you to know that neutral solutions have $H^{+}_{(aq)}$ ions in them, too.

3. What is the source of $H^{+}_{(aq)}$ ions in a neutral solution?

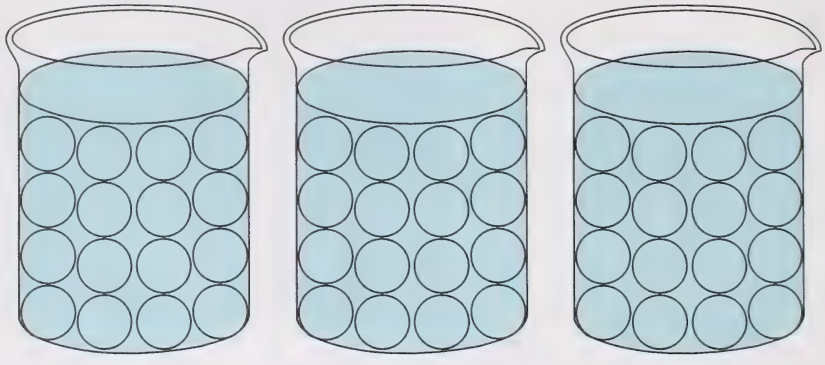
Check your answers by turning to the Appendix, Section 1: Activity 3.

The final surprise is that even basic solutions contain $H^{+}_{(aq)}$ ions – but relatively few.

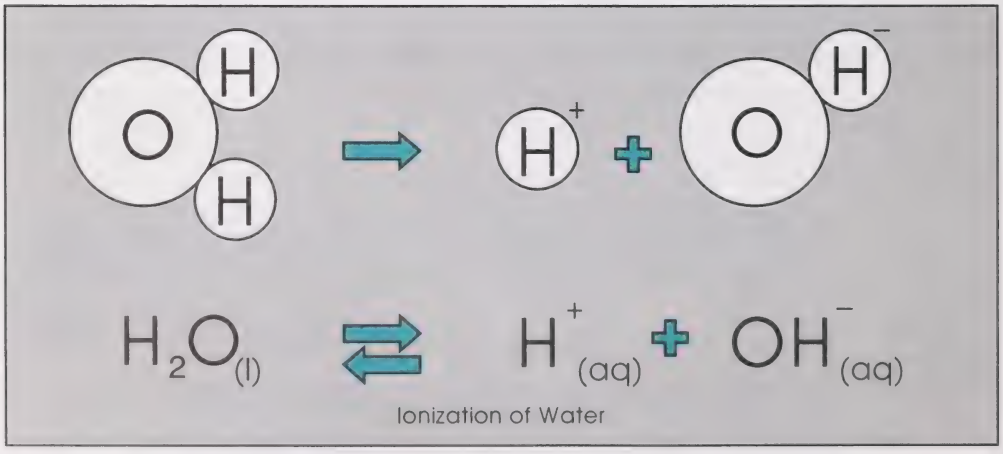
$\left[H^{+}\right]$	$\left[H^{+}\right]$	$\left[H^{+}\right]$
$\left[OH^{-}\right]$	$\left[OH^{-}\right]$	$\left[OH^{-}\right]$
pH = 1	pH = 7	pH = 13

Answer the following question to clarify the relationships between acidic and basic solutions and $\left[H^+_{(aq)}\right]$ and $\left[OH^-_{(aq)}\right]$.

4. The models of the following solutions have circles in them representing ions. Write H^+ or OH^- symbols in an appropriate number of circles in each solution to represent the real relationships between H^+ and OH^-.



The previous questions and models emphasize the fact that no matter whether the solution is acidic, basic, or neutral, both $H^+_{(aq)}$ ions and $OH^-_{(aq)}$ ions are present. This is because all of the solutions you will deal with contain water. Water has its own equilibrium (a term from Module 1) that contains both $H^+_{(aq)}$ and $OH^-_{(aq)}$ ions.



Ionization of Water

It is, therefore, possible for you to characterize any solution by the amount of H^+ ions present. As you have already read on page 131 of your textbook, this description of solutions is done by pH.

5. a. What pH values correspond to acidic solutions?

   b. What pH values correspond to basic solutions?

Check your answers by turning to the Appendix, Section 1: Activity 3.

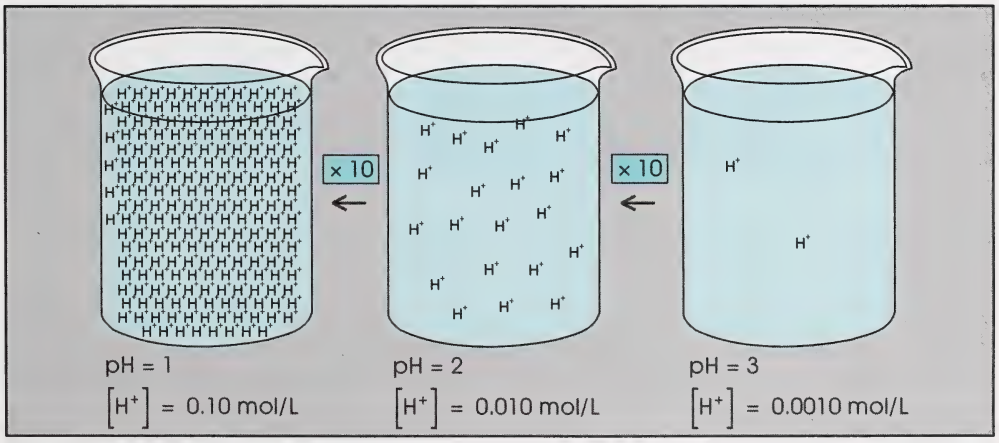
Most of the solutions you would see in nature, in the lab, and in industry have concentrations of $H^+_{(aq)}$ ions in the range of 1×10^{-1} mol/L to 1×10^{-14} mol/L. These numbers, with negative powers of ten, are inconvenient to work with in calculations.

The pH scale is a convenient way to represent $\left[H^+_{(aq)}\right]$ because you don't have to work with exponents. The pH scale, as you have seen, is based on multiples of 10.

6. a. Solution A has a pH = 1 and Solution B has a pH = 3. How many pH units apart are Solutions A and B?

   b. By what factor of 10 do the $\left[H^+\right]$s in the two solutions differ?

Check your answers by turning to the Appendix, Section 1: Activity 3.



You can make the following generalizations based on the preceding information.

Solution	$\left[H^+_{(aq)}\right]$ (mol/L)	pH
Acidic	$> 10^{-7}$	< 7
Neutral	$= 10^{-7}$	= 7
Basic	$< 10^{-7}$	> 7

Values of pH below seven are acids and above seven are bases, but what does the size of a pH number mean in terms of how acidic or basic a solution is? Complete the following questions to get a better idea of what the size of a pH number means.

7. Fill in the following chart.

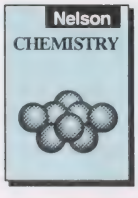
$[H^+]$ (mol/L)	pH	Acidic/Basic/Neutral
10^{-4}	4	
10^{-7}		neutral
	10	basic
10^{-2}		
	9	
10^{-12}		
	3	
10^{-8}		

8. Which is a larger $[H^+_{(aq)}]$, 10^{-8} mol/L or 10^{-10} mol/L?

9. Which has a larger pH, $[H^+_{(aq)}] = 10^{-8}$ mol/L or $[H^+_{(aq)}] = 10^{-10}$ mol/L?

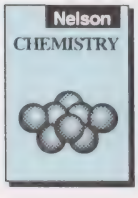
10. a. What does a very large pH number mean in terms of the size of the $[H^+_{(aq)}]$ of the solution?

    b. What does a very small pH number mean in terms of the size of the $[H^+_{(aq)}]$?



11. To gain practice in pH and $[H^+_{(aq)}]$ calculations, turn to page 132 in your textbook and complete questions 23, 24, 25, and 26.

Check your answers by turning to the Appendix, Section 1: Activity 3.



So far, you have been working with whole number powers of ten and whole number pH values. However, this will not always be the case. To illustrate with an example, look at Figure 5.11 on page 131 of your textbook and estimate the pH value for a soft drink.

Your pH estimate for the soft drink was probably 3.5 or 3.6. This decimal part of the pH value, the .5 or .6, creates an $H^+_{(aq)}$ concentration that is no longer expressed as just a whole number power of ten.

pH	$\left[H^+_{(aq)}\right]$ (mol/L)
3.5	3×10^{-4} ↑ (results from the decimal portion of the pH value)

As you can see, the decimal part will make the calculation of pH from $\left[H^+_{(aq)}\right]$, as well as $\left[H^+_{(aq)}\right]$ from pH, a bit more complicated. You will learn about these types of pH values when you take Chemistry 30.

You have already seen the definition of pH.

$$pH = -\left(\log\left[H^+_{(aq)}\right]\right)$$

Why is the negative sign in the definition? You can answer this question by looking at the hydrogen ion concentrations you have worked with so far. The hydrogen ion concentrations almost always have negative powers of ten. Therefore, to make pH numbers easier to work with, you multiply the power of ten value for the $\left[H^+_{(aq)}\right]$ by negative one (– 1): $pH = -\left(\log\left[H^+_{(aq)}\right]\right)$

↑ (means multiply by – 1)

$\left[H^+_{(aq)}\right] \rightarrow pH$	$pH \rightarrow \left[H^+_{(aq)}\right]$
↓	↓
$pH = -\left(\log\left[H^+_{(aq)}\right]\right)$	$\left[H^+_{(aq)}\right] = \text{antilog} - pH$

Now that you see how the pH scale can make your analysis of a solution more specific, you will do an investigation using universal pH paper. Litmus tells you if a solution is acidic or basic, but universal pH paper tells you the pH of a solution more precisely. (It is still only an approximation!)

Investigation: Qualitative Analysis of Unknown Solutions

Science Skills

- [x] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

In this investigation you will be doing tests on five unknown solutions involving a conductivity apparatus and universal pH paper. Universal pH paper turns different colours depending on the pH value.

Carefully follow the directions given for this investigation. Pay special attention to the required components, safety aspects, and applied science skills.

Guidelines

- Do not allow any of the solutions to touch your skin. One is a strong acid and another is a strong base.
- For the sucrose solution, dissolve 1 mL (1/4 tsp. or a pea-sized amount) of white table sugar into 10 mL of distilled H_2O.

Problem

Which of the 0.10 mol/L solutions labelled 1, 2, 3, 4, and 5 are $C_{12}H_{22}O_{11(aq)}$, $HCl_{(aq)}$, $CH_3COOH_{(aq)}$, $KOH_{(aq)}$, and $KBr_{(aq)}$?

12. Write a brief description of your design.

Materials

- 10 mL each of the following 0.10 mol/L solutions labelled as UNKNOWN 1-4
  - hydrochloric acid, $HCl_{(aq)}$
  - acetic acid (vinegar), $CH_3COOH_{(aq)}$
  - potassium hydroxide, $KOH_{(aq)}$
  - potassium bromide, $KBr_{(aq)}$
- 1 mL (1/4 tsp.) sucrose (sugar), $C_{12}H_{22}O_{11(s)}$ in 10 mL of water (prepared yourself)
- conductivity apparatus
- universal pH paper (hydrion paper) and standard colour chart
- test tubes (or suitable containers)
- distilled water

Procedure

13. List the steps in your procedure. Label the sucrose solution test tube 5.

14. Draw a data table that allows you to record your observations of conductivity and pH values for each of the five solutions.

Analysis

15. As your analysis, summarize the results by identifying each unknown solution. State a reason for each conclusion.

Check your answers by turning to the Appendix, Section 1: Activity 3.

indicator – a weak acid that changes colour when it ionizes

You just used a piece of paper to get the approximate pH of a solution. This is a good example of using an **indicator** to determine pH.

You have used an indicator before to test acidity or basicity – litmus!

There are many examples of pH values that litmus cannot distinguish between. As a tool for correct pH determination, its uses are limited.

16. Give an example of two pH values that litmus could be used to distinguish between.

17. Give an example of two pH values that litmus could not distinguish between.

Check your answers by turning to the Appendix, Section 1: Activity 3.

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There are a variety of different indicators. They each have their own colour range – a narrow range of pH values in which they change colour. Indicators can be chosen to cover the entire range of the pH scale – from pH 1 to pH 14. A table of indicators, Acid-Base Indicators, is given to you on the inside back cover of your textbook.

Figure 2.2 shows examples of four indicators.

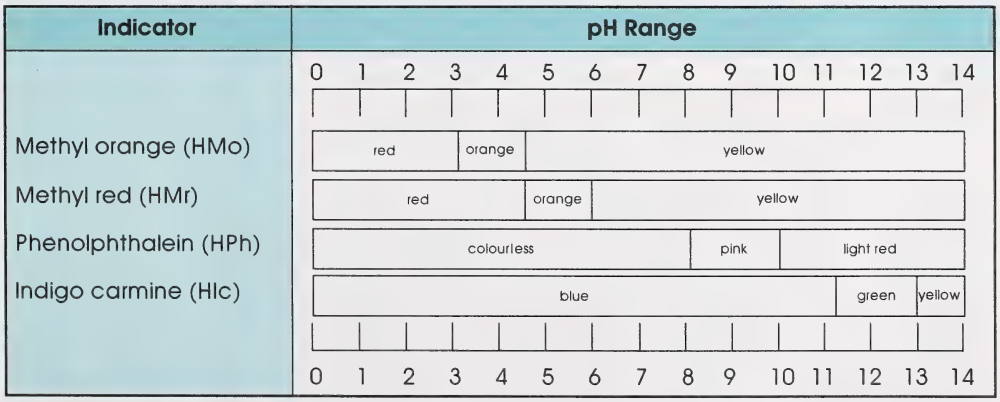


FIGURE 2.2: Colour pH Ranges of Common Indicators

The choice of the correct indicator can give you a narrower range of possible pH values than litmus. This allows you to find the pH of a solution more precisely.

Refer to Figure 2.2 and answer the following two questions.

18. If methyl orange is red, the pH of a solution must be _____. (Give a range of pH, not a simple value.)

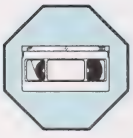
19. What colour would indigo carmine be if placed in an $NaOH_{(aq)}$ solution of pH = 12?

You can narrow down the pH further if you use more than one indicator with the same solution. The universal pH paper that was used in the previous investigation is a combination of indicators. This pH paper allowed you to determine the pH more precisely. The following two questions use Figure 2.2 and more than one indicator to determine the pH of a solution.

20. If HMo is yellow in a solution and HMr is red in the same solution, what is your best estimate of the pH of the solution?

21. If HMo is yellow, HMr is yellow, HPh is colourless, and HIc is blue in a solution, what is the pH of the solution?

Check your answers by turning to the Appendix, Section 1: Activity 3.



Acid-Base chemistry is prevalent in all aspects of your life. It is important to understand both the good and the bad sides of substances such as acids and bases. For a brief look at some examples of everyday acids and bases, view the video Acids and Bases *(World of Chemistry Series)*. This video introduces many examples of acids and bases, shows some of the effects of acid-base chemistry, and reviews some of the basic concepts you studied in this section. It is recommended that you preview the following questions before watching the video.

22. List three ways lime (CaO) is used to reduce the effects of acids in the environment and in industry.

species – a term denoting an atom, ion, or compound

23. What **species** is common in all aqueous acid-base reactions?

Note: In the video the term *hydronium ion* $\left(H_3O^+_{(aq)}\right)$ is used. This is the way that hydrogen ions $\left(H^+_{(aq)}\right)$ are thought to exist in the presence of water.

$$H^+ + H_2O \rightarrow H_3O^+$$

24. a. What is the purpose of a pH meter?

    b. How does the pH meter work?

25. What is the difference between a strong and a weak acid?

26. a. What causes acid rain?

    b. What are some of the effects of acid rain?

    c. What is society doing about acid rain?

Check your answers by turning to the Appendix, Section 1: Activity 3.

corrosive – the ability to cause oxidation (loss of electrons)

caustic – a substance that burns or destroys organic tissue

You have seen that pH is just another way of expressing the strength of acids and bases. Values of pH are often as low as 0 and as high as 14. A solution with a pH = 0 is a very **corrosive** acid, and a solution with a pH = 14 is a very **caustic** base. Solutions with these pH values, however, are transported on the highways and through cities every day. Strong acids and bases are in great demand in industry. To be economical they must be transported in a concentrated form.

Have you ever seen a large tanker truck with Muriatic Acid written on the side, or Anhydrous Ammonia, or Sulphuric Acid? These are fairly common sights on the highways of Alberta.

As you can imagine, it is dangerous to transport these chemicals. Figure 2.3 summarizes some of the risks and benefits of transporting strong acids and bases through populated areas.

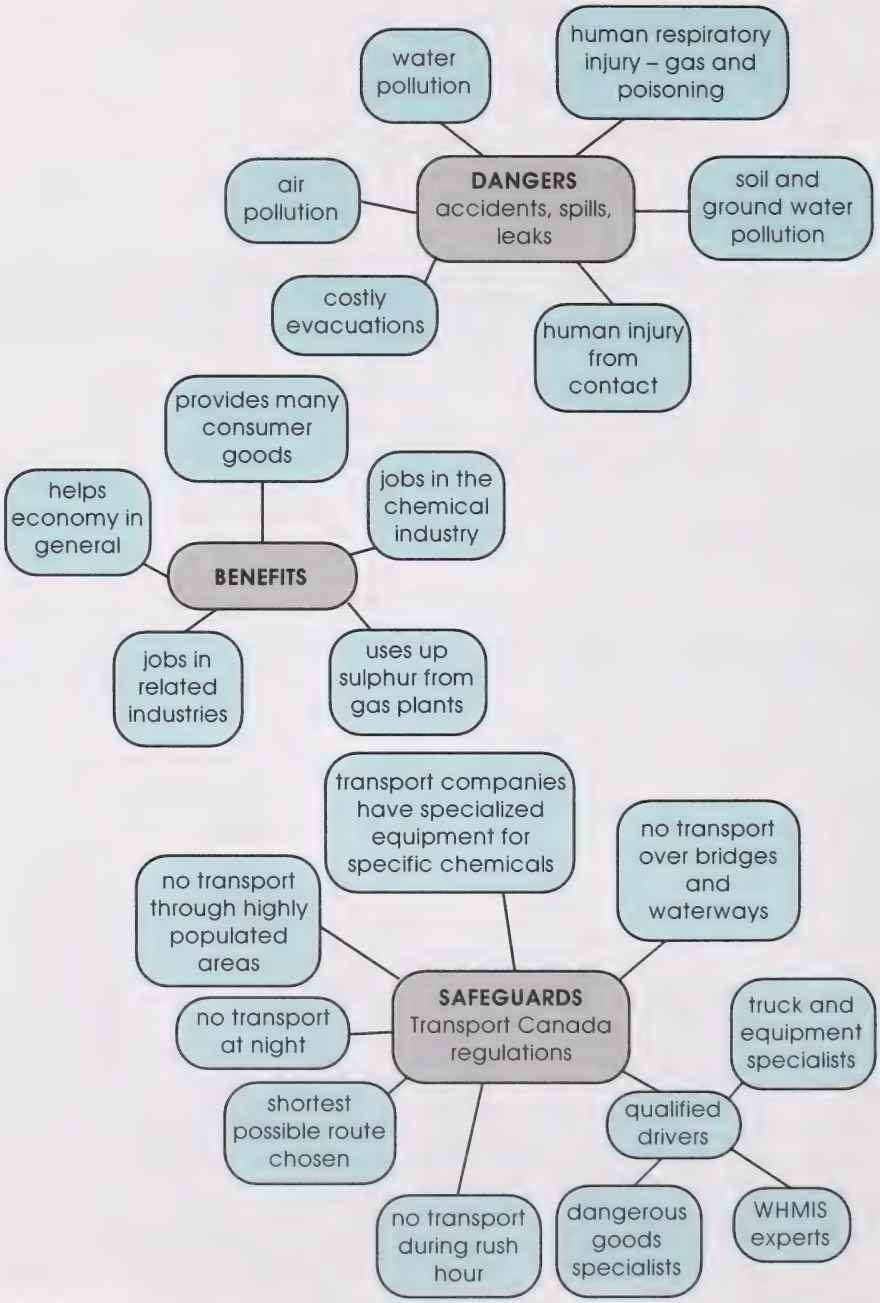


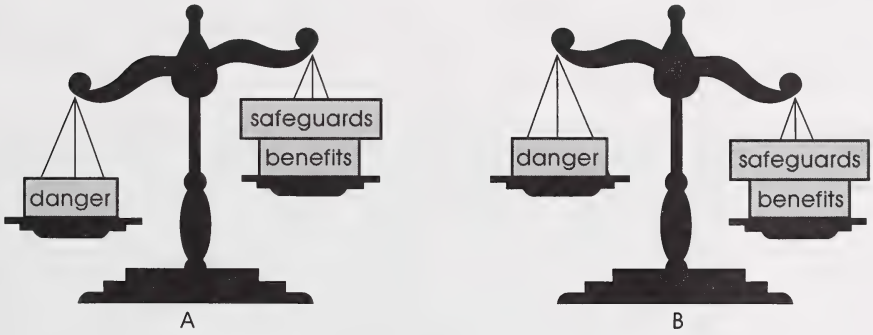
FIGURE 2.3: Dangers, Safeguards, and Benefits of Transporting Dangerous Acids and Bases

After studying Figure 2.3 and considering the dangers, safeguards, and benefits of the transport of dangerous acids and bases, answer the following questions.

27. Construct a chart on your own paper similar to the one shown. Then use check marks to identify the appropriate properties of each item.

Item	Dangerous	Needs Safeguards	Has Benefits	Generally Good	Generally Bad
Orange juice					
Concentrated H_2SO_4					
Distilled water					
Vinegar					
Lime					

28. a. In your assessment of dangers, safeguards, and benefits, which of the following illustrations represents your findings towards the transport of dangerous chemicals through cities?



b. Give two reasons explaining your choice.

29. What other knowledge would you need to make a decision as to whether the safeguards in Figure 2.3 are good enough?

30. What WHMIS symbols would you expect to see at a site producing H_2SO_4?

Check your answers by turning to the Appendix, Section 1: Activity 3.

You have discovered how the whole range of acidity → neutrality → basicity can be expressed by using pH. You also saw how indicators can be used to characterize the acidic or basic nature of a solution to within narrow ranges of pH.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

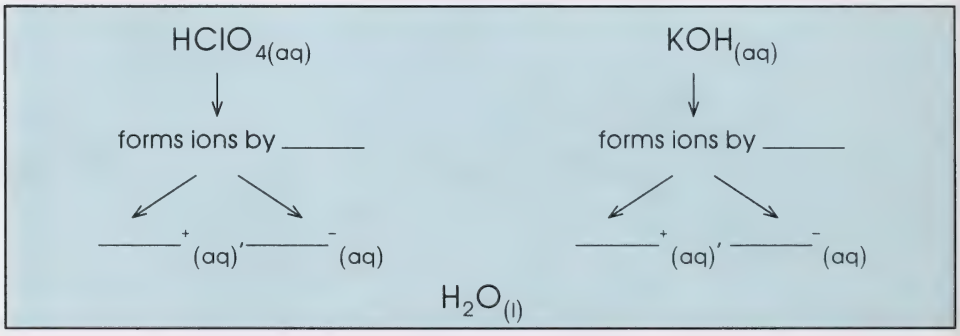
There are three main topics addressed in this section. They can be summarized in the following questions.

1. Complete the empirical definitions of acids and bases by finishing each chart.

Acids
• turn litmus red

Bases
• turn litmus blue

2. Construct a diagram showing acid-base neutralization similar to the following. Label the steps and fill in the blanks. Then draw arrows from the appropriate ions to form $H_2O_{(l)}$.



3. Identify the statements as being either true or false. Correct the false statements.

   a. The pH of a solution gets larger as it gets more basic.

   b. Litmus always gives a very good idea of what the pH of a solution is.

   c. A solution of pH = 7 has equal numbers of $H^+_{(aq)}$ and $OH^-_{(aq)}$ in it.

   d. An acid of pH = 1 is mixed with a base of equal volume of pH = 13. The final pH = 14.

e. The $\left[H^{+}_{(aq)}\right]$ in a solution of pH = 3 in 1000 times greater than the $\left[H^{+}_{(aq)}\right]$ of a solution of pH = 6.

4. Read each phrase and decide whether it describes an acid (A), a base (B), or both an acid and base (A and B).

a. tastes bitter

b. found in many things you eat

c. used in the production of fertilizer

d. keeps your house clean

e. very dangerous; needs extreme caution in handling

f. need goggles when dealing with high concentrations of them

g. used to make soap

h. forms ions in solution

i. forms clear solutions

j. likes to dissociate

k. ionizes poorly when weak but well when strong

l. effects reduced by using a little base neutralizer

5. Construct a table similar to the following and fill in the missing information.

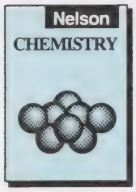
$\left[H^{+}_{(aq)}\right]$ (mol/L)	pH	Acid/Base/Neutral
10^{-1}		
10^{-2}		
	3	
10^{-4}		
	5	
	6	
10^{-7}		
	8	
10^{-9}		
10^{-10}		
	11	
	12	
10^{-13}		
	14	

6. Using Figure 2.3, which describes the handling of dangerous acids and bases, list three examples for each of the following categories: Dangers, Safeguards, and Benefits. Construct your own chart to organize the information.

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Complete **one** of the following questions.



1. There are many perspectives from which you can look at acid rain. These perspectives are outlined on page 107 of your textbook. Expand on either the scientific perspective or the technological perspective.

   If you expand on the scientific perspective, obtain the actual chemical reactions that lead to the formation of the acids in acid rain. Then find actual chemical reactions that show how these acids damage statues and water pipes.

   If you expand on the technological perspective, find actual chemical reactions that describe how attempts are made to reduce the amounts of oxides released into the atmosphere.

2. Sulphuric acid is the most widely used compound in the chemical industry. The process used to produce it is known as the **contact process**. Find out how the process works in more detail.

   If you live close to Fort Saskatchewan, it may be possible for you to arrange a field trip to the C-I-L Inc. plant where H_2SO_4 is produced.

3. The only acid that cannot be stored in a glass container is hydrofluoric acid. Find out how it reacts with glass and how this reaction supports the glass-etching industry.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have learned how acids and bases behave and the theory behind why they behave this way. You have seen that the potential danger of acids and bases varies due to differences in strength and concentration. Many strong and weak acids and bases are found in your home. You should now be able to recognize these chemicals on product labels and deal with them safely.

40

Section 1 Assignment: Acids and Bases

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Chemistry 20 – Module 2 Section 1 Assignment Page # Name and ID #

Be sure to write legibly. Leave a wide left margin and number all of your pages.

1. How do the concentrations of $H^+_{(aq)}$ and $OH^-_{(aq)}$ compare in each of the following? **(2 marks)**

   a. an acidic solution

   b. a neutral solution

2. Classify each of the following substances as an Arrhenius acid, an Arrhenius base, or a neutral substance. **(3 marks)**

   a. CH_3OH b. HNO_2 c. C_5H_9COOH

3. Indicate what the dominant species are when each of the following substances is mixed with water. Include states. **(4 marks)**

   a. C_2H_5OH

   b. $BaSO_4$

   c. $HClO_3$

   d. HI

4. A solution has the following characteristics: it turns litmus blue, tastes bitter, neutralizes bases, and is an electrolyte. Which of these solution characteristics doesn't fit with the others? **(1 mark)**

5. Name the following acids and bases: **(4 marks)**

   a. $HF_{(aq)}$

   b. $H_3BO_{3(aq)}$

   c. $CsOH_{(s)}$

   d. $HCN_{(aq)}$

6. Write balanced chemical equations for the double replacement neutralization reactions of the following aqueous acids and bases. Include states. **(2 marks)**

   a. calcium hydroxide and phosphoric acid

   b. ammonium hydroxide and sulphurous acid

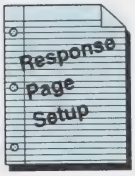
7. Is a base burn on your hand best treated for neutralization with a strong acid or a weak acid? Give reasons for your answer. **(2 marks)**

8. Write a dissociation equation or an ionization equation to represent what happens when each of the following solutions is made. Then calculate the concentrations of all the ions. Show your work. **(6 marks)**

   a. 0.061 mol/L $Ba(OH)_2$

   b. 0.87 mol/L HNO_3

   c. 1.06 mol/L $(NH_4)_2SO_4$



9. On your response page develop a chart similar to the one following. Fill in the missing information. **(4 marks)**

$[H^+_{(aq)}]$(mol/L)	pH	Acid/Base/Neutral	Colour of Litmus
	11		
10^{-5}			
	3		
10^{-8}			

10. One solution has a pH of 4 and another has a pH of 7. Calculate the $[H^+_{(aq)}]$ of each solution and determine how many times higher the $[H^+_{(aq)}]$ is in the stronger acid. **(2 marks)**

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☑ F. Evaluating

11. Five solutions were made with concentrations of approximately 0.10 mol/L of solute. The solutions were tested with a conductivity apparatus and their pH values were measured. The experimental evidence was as follows:

Solution Number	1	2	3	4	5
pH	7	7	1	13	5
Conductivity	no	yes	yes	yes	weak

The solutions were known to be $C_2H_5OH_{(aq)}$, $HClO_{4(aq)}$, $H_3BO_{3(aq)}$, $CsOH_{(aq)}$, and $KNO_{3(aq)}$.

Answer the following questions based on the preceding information. **(5 marks)**

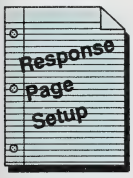
a. Which solution had to be the $C_2H_5OH_{(aq)}$?

b. What was the $[H^+_{(aq)}]$ of the $HClO_{4(aq)}$?

c. What was the $\left[H^{+}_{(aq)}\right]$ of the $H_3BO_{3(aq)}$?

d. Which solution could best neutralize Solution 4?

e. Which solution could best be used to neutralize a base that was accidently splashed on your skin?



Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

Self:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F. ☐
Teacher:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F. ☐

12. a. Drain cleaner contains sodium hydroxide. What are two safety measures that should be written on the label of the container? **(2 marks)**

b. What could be done if drain cleaner got into someone's eyes? **(1 mark)**

13. In Alberta there are special teams that respond to accidents involving the transport of dangerous chemicals. What are two skills these teams must have? **(2 marks)**

SECTION 2

Gases

Courtesy of Roy Steele

You have just been hit by a nitrogen molecule going about 1770 km/h. Did you feel it? Of course not. It was too small. Nitrogen gas molecules are so small that a deep breath takes in about 4×10^{22} of them!

You are surrounded by billions of molecules of gas. You walk through them, sleep in them, breathe them in, and feel them blow through your hair. Have you ever wondered how these same tiny gas molecules can make a tire as hard as a rock or destroy homes and buildings in a tornado?

In Section 2 you will learn about gaseous properties and the empirical laws that govern the physical behaviour of gases. You will also see how careful experimentation led to the formulation of these gas laws. As well, you will discover how gases behave under ideal conditions.

ACTIVITY 1

Gaseous Properties

How are gases important to you? With every breath you take, you inhale one type of gas (oxygen) and exhale another (carbon dioxide). Sulphur dioxide, $SO_{2(g)}$, is used to make sulphuric acid – an important compound in industry. Ammonia, $NH_{3(g)}$, is another important gas involved in the production of fertilizers.

1. List two other examples of gases you are aware of and their uses to society.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Because of the importance of gases, it is useful for you to know their properties.

Nelson CHEMISTRY

You should have developed a good mental picture of what gases are like from your study of the kinetic molecular theory (KMT) in Science 10.

To make sure you remember what the KMT says about the nature of matter, go to your textbook and read page 93 and the top of page 94. Then answer the following questions.

2. Identify which statements support the kinetic molecular theory.

   a. Sugar dissolves in coffee even if you don't stir it.

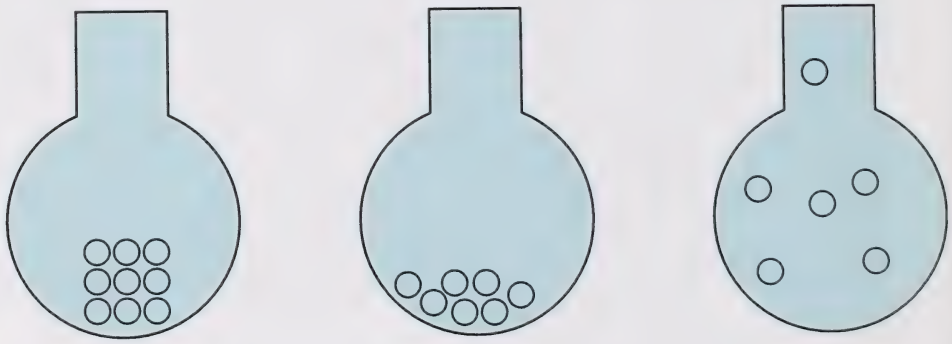
   b. You can smell the livestock pens kilometres away.

   c. The mass of a rock can remain unchanged for centuries.

   d. Random motion of smoke particles is called Brownian motion.

   e. The temperature of the water at the bottom of a lake can be several degrees colder than at the top of a lake.

3. In which container are the atoms or molecules most isolated or independent?



4. What aspect of the KMT do the following examples illustrate?

   a. One mole of dry ice $\left(CO_{2(s)}\right)$ takes up 28 mL of volume, but one mole of $CO_{2(g)}$ takes up 25 000 mL.

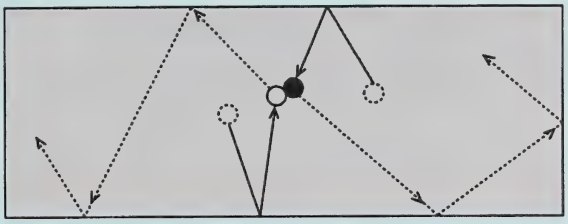
   b. One tank of $He_{(l)}$ can fill up over 500 large balloons.

Check your answers by turning to the Appendix, Section 2: Activity 1.

As the preceding questions illustrate, the gas phase is the only one of the three phases of matter where atoms or molecules are far apart from each other. You will be surprised how similar this independence makes their physical properties.

How do you think particles of a gas behave? You may think of billiard balls or ping-pong balls. The KMT becomes more detailed in its description of the behaviour of gas molecules. The theoretical assumptions about their behaviour are summarized in Figure 2.4.

- Molecules and atoms of gases are particles of negligible volume compared to the spaces between them. (Picture in your mind the relative size of an ant on the surface of the Earth as viewed from space.)
- Gas particles do not attract or repel each other.
- Gas particles move in straight lines except when they collide with other particles or the sides of the container.



- Collisions of gas particles are perfectly elastic. No energy is lost on collision.

FIGURE 2.4: Characteristics of Gas Particles

The preceding theoretical assumptions about the behaviour of gas particles can help you explain the empirical behaviours of gases and some of the everyday experiences you have with gases.

For a description of the physical properties of gases, read the top of page 143 in your textbook. Then answer the following questions.

5. Write the appropriate theoretical characteristics from Figure 2.4 that describe each of the following empirical properties.

Empirical Property	Theoretical Characteristic of Gases
Gases completely fill containers.	
Gases are compressible.	
Gases can diffuse through each other.	

diffuse to move and spread freely

6. Match the appropriate empirical property of a gas with each fact about gases.

A – Gases fill containers. B – Gases are compressible. C – Gases diffuse.

a. Airbags save lives.

b. You can smell popcorn cooking.

c. Gases are sold by mass not volume.

d. Toxic gas leaks are more difficult to clean up than liquid ones.

e. A tire can make bumps in the road feel smoother.

f. A jar with one mole of hydrogen in it is indistinguishable from one with two moles of hydrogen in it.

g. Gas can be pumped into a tire.

Check your answers by turning to the Appendix, Section 2: Activity 1.

You have seen how the theoretical definition of gases (KMT) helps people understand the properties of gases. Now you will look more closely at two of the empirical properties of gases. Do the following investigation on the compressibility of gases.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Investigation: The Compressibility of Gases

In this investigation you will be testing air to see how easily gases are compressed. While performing the investigation, pay special attention to the required components, safety aspects, and applied science skills.

Purpose

The purpose of this investigation is to demonstrate the compressibility of gases.

Design

You will exert pressure on some confined air in an eye dropper that is placed inside a graduated cylinder.

Guidelines

- Do not push on the glass hard enough to break it.

Materials

- eye dropper
- water
- 100 mL graduated cylinder or narrow-necked glass

Procedure

- Fill the graduated cylinder or container about three-quarters full of water.
- Draw a little water into the eye dropper; then see if the dropper floats in your container. If the eye dropper sinks, force out a little water until it barely floats. If it floats, let in a little more water until it barely floats.
- Cover the top of the container with your hand making a seal with your palm.
- Exert a little pressure and observe what happens. If nothing happens, let more water into the dropper and repeat the procedure.

7. To show your evidence, write a description of what occurred, or draw a diagram.

Analysis

Complete the following questions as part of your analysis.

8. Was it difficult or easy to compress the gas in the eye dropper? Why or why not?
9. Did the liquid in the container, or the container itself, compress or swell?
10. According to the KMT, why did the gas compress but not the liquid or solid?

Check your answers by turning to the Appendix, Section 2: Activity 1.

The same qualities that allow gases to compress also allow them to diffuse.

Have you ever seen a skunk? Even if you haven't, you have probably experienced its presence. Do the following investigation on diffusion. You will discover why you don't have to see a skunk to know it's been around.

Investigation: Diffusion

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

In this investigation you will be looking at the diffusion of two gases, $NH_{3(g)}$ and $HCl_{(g)}$. While performing this investigation, pay special attention to the required components, safety aspects, and applied science skills.

Purpose

The purpose of this investigation is to see evidence for the diffusion of gases.

Design

Measurements of $NH_{3(g)}$ and $HCl_{(g)}$ movements within a tube are made by noting their point of reaction.

Guidelines

Caution

- Wear safety goggles and a lab coat (apron) throughout the investigation.
- Do not allow concentrated $NH_{3(g)}$ or $HCl_{(g)}$ to touch your skin.

Materials

- concentrated $NH_{3(aq)}$, $(NH_4OH_{(aq)})$
- concentrated $HCl_{(aq)}$
- cotton batting
- long piece of glass tubing 0.5 cm-2 cm in diameter and 1 m in length
- metre stick
- eye dropper

Procedure

- Lay the tube on a flat surface.
- Put a few drops of concentrated $HCl_{(aq)}$ about 3 cm in from one end of the tube and a few drops of concentrated $NH_{3(aq)}$ about 3 cm in from the other end of the tube. Immediately plug the ends with cotton batting.
- Observe the tube carefully and record your evidence.

11. a. Describe what happened in the investigation, or draw a diagram of your observations.

    b. Record the distance from the start of $HCl_{(g)}$ to the precipitate and the distance from the start of $NH_{3(g)}$ to the precipitate.

As part of your analysis, complete the questions following Part B.

Check your answers by turning to the Appendix, Section 2: Activity 1.

End of Part A

Part B

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

In this investigation you will be looking at the diffusion of two gases, $NH_{3(g)}$ and $HCl_{(g)}$. While studying this investigation, pay special attention to the required components, safety aspects, and applied science skills. If you were to actually perform this investigation, the following guidelines, materials, and procedure would be followed. Read them carefully.

Purpose

The purpose of this investigation is to see evidence for the diffusion of gases.

Design

Measurements of $NH_{3(g)}$ and $HCl_{(g)}$ movements are made by noting their point of reaction.

Caution

Guidelines

- Wear safety goggles and a lab coat (apron) throughout the investigation.
- Do not allow concentrated $NH_{3(g)}$ or $HCl_{(g)}$ to touch your skin.

Materials

- concentrated $NH_{3(aq)}$, $\left(NH_4OH_{(aq)}\right)$
- concentrated $HCl_{(aq)}$
- cotton batting
- long piece of glass tubing 0.5 cm-2 cm in diameter and 1 m in length
- metre stick
- eye dropper

Procedure

- Lay the tube on a flat surface.
- Put a few drops of concentrated $HCl_{(aq)}$ about 3 cm in from one end of the tube and a few drops of concentrated $NH_{3(aq)}$ about 3 cm in from the other end of the tube. Immediately plug the ends with cotton batting.
- Observe the tube carefully and record your evidence.

12. To obtain the observations for this investigation, consult question 11, Section 2, Activity 1 in your Appendix. Copy the observations onto your own paper.

End of Part B

Analysis

13. Which gas, $NH_{3(g)}$ or $HCl_{(g)}$, diffused the fastest? How do you know?

14. Gas molecules at room temperature move thousands of kilometres per hour. Why did it take so long for the $NH_{3(g)}$ and the $HCl_{(g)}$ molecules to reach each other?

15. a. What do you think the white precipitate was that formed?

    b. Why was the product a solid?

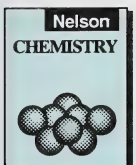
Check your answers by turning to the Appendix, Section 2: Activity 1.

You have seen how the kinetic molecular theory helps explain empirical phenomena like the compressibility of gases and their ability to diffuse. With this new information in mind you will probably never think about air shocks in cars or smelling dinner burning in the same way again.

ACTIVITY

2 Boyle's Law

Nelson CHEMISTRY



How would you like to blow up balloons by mouth for a living? Sometimes it is really difficult to inflate a balloon. When you do finally get enough air in the balloon, though, it keeps the balloon inflated. How is this possible? Read the bottom half of page 150 and the top paragraph on page 151 in your textbook to gain some insight.

1. According to the kinetic molecular theory, how can a gas exert pressure?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Not only air in a balloon can exert gas pressure – so can air in the atmosphere. Have you ever heard the weatherperson say that the atmospheric pressure was falling and you were in for a storm?

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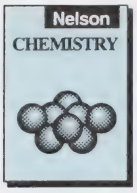
If the atmosphere didn't exert pressure, you wouldn't be able to drink a milkshake with a straw. It is atmospheric pressure that pushes the fluid up the straw to your mouth. What exactly makes that milkshake flow up the straw?



To see how much pressure the atmosphere can exert, and what units pressure is measured in, read the bottom of page 143 and the top of page 144 in your textbook. Then answer the following questions.

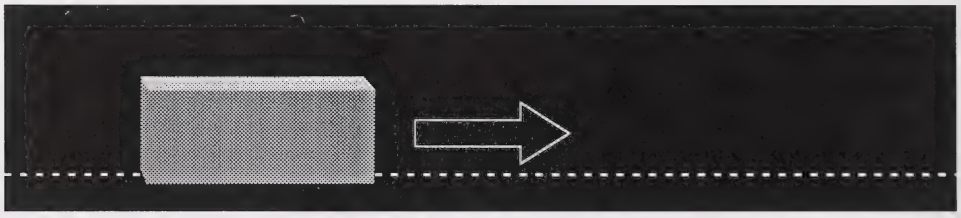
2. Classify the following as either a high-pressure or low-pressure situation, and explain your answer.

   a. A firefighter lays flat on the ice and tries to save a dog from the cold water.

   b. You get your foot stepped on by a person wearing high heels.

   c. You cross-country ski over deep snow.

3. Draw a picture showing how you would place the following brick so that it exerts the most pressure.



4. Match the following pressures to the appropriate locations: 97 kPa, 33 kPa, 27 kPa, and 101 kPa.

Location	Pressure
Calgary	
Vancouver	
Mt. Everest	
High in an airplane	

5. Given that one kilopascal is defined as 1000 N (newtons) of force exerted on a square metre (1 kPa = 1000 N/m^2), how many kilopascals of pressure would a piece of plywood one metre square (1 m^2) exert on the ground if you were standing on it? (To convert your weight to newtons, use the following conversions: 1 kg = 9.8 N; 1 kg = 2.2 lb.)

Check your answers by turning to the Appendix, Section 2: Activity 2.

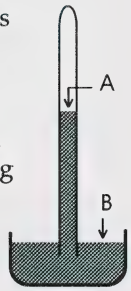
Nelson CHEMISTRY

Read the text in the right-hand margin of page 143 of your textbook to see what is used to measure atmospheric pressure. Then answer the following questions to make sure you understand how the device works.

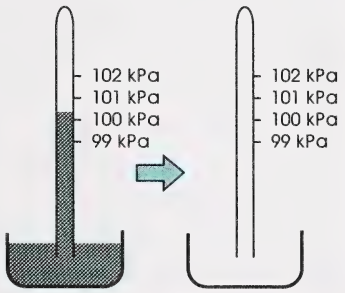
Frame 425

If you have access to the laser videodisc *Cosmic Chemistry*, disc side 6, find and view frame 425, a photograph of Evangelista Torricelli.

6. a. What pushes on the mercury at point A and at point B in the following diagram?



b. The following is a barometer at sea level. Draw what would happen to the barometer if it was moved to Banff, Alberta.



Check your answers by turning to the Appendix, Section 2: Activity 2.

The barometer is a good instrument for measuring atmospheric pressure, but not for measuring the pressure of confined gases in the lab. To measure the pressure of confined gases, you need to use a **manometer**. There are many types of manometers. One type is shown in Figure 2.5.

manometer – an instrument used to measure the pressure of a confined gas

The manometer in Figure 2.5 works by comparing the pressure of the atmosphere to the pressure of the gas sample in the bulb.

7. Does the gas sample or the atmosphere have the higher pressure in Figure 2.5?

8. How can you tell whether the gas sample or the atmosphere has the higher pressure in Figure 2.5?

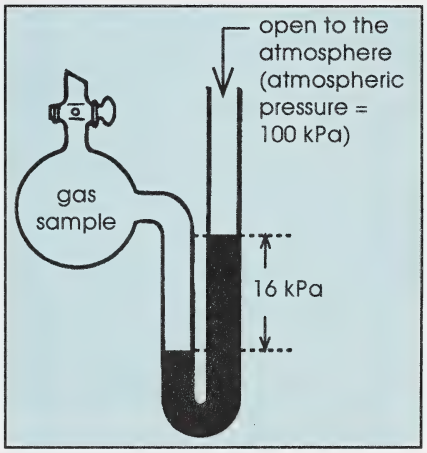
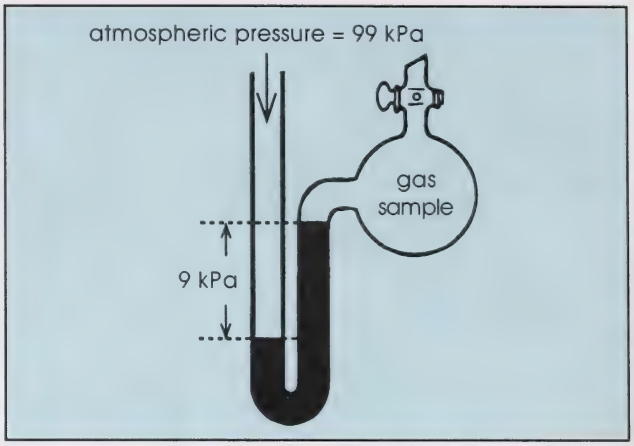


FIGURE 2.5: The Manometer

Check your answers by turning to the Appendix, Section 2: Activity 2.

Since the gas in the manometer in Figure 2.5 exerts 16 kPa more pressure than the atmosphere, the pressure of the gas sample is 16 kPa plus atmospheric pressure, or
16 kPa + 100 kPa = 116 kPa.

9. To make sure you can read a manometer, determine the pressure of the gas sample in the manometer on the right.



Check your answers by turning to the Appendix, Section 2: Activity 2.

Nelson CHEMISTRY

Gases are not only dramatically affected by pressure but also by changes in temperature. You can read at the top of page 144 of your textbook that the conditions for working with gases are standardized in terms of STP and SATP.

10. a. Complete the chart.

Condition	Temperature	Pressure
SATP		
STP		

b. Which term describes conditions most like those encountered in a normal room (or a science lab) – SATP or STP?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Nelson CHEMISTRY

Have you ever had a sharp pain in your ears when you dove deep into water? Conditions are certainly not standard there! Scuba divers have to be particularly careful of the relationship between pressure and volume of gases. If divers are not careful, and they rise from the depths too quickly, high gas pressure can rupture their lungs.

The relationship between pressure and volume was discovered by Robert Boyle (Boyle's law). Refer to the margin on page 144 of your textbook for a picture of Robert Boyle.

Do the following investigation to develop an understanding of Boyle's law. While performing the investigation, pay special attention to the required components, safety aspects, and applied science skills.

When performing the investigation, you may have to experiment a little with the equipment to get the best results.

Investigation: The Effect of Pressure on the Volume of a Gas (Boyle's Law)

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A

Purpose

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

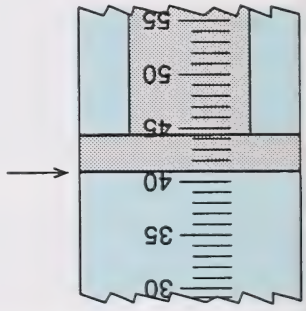
The purpose of this investigation is to determine the relationship between pressure and volume of a gas.

Design

A fixed quantity of air will be trapped in a syringe. Pressure on the plunger will be varied and the volume recorded.

Guidelines

- Use textbooks (as masses) that are about 2 cm-3 cm in thickness. Since the mass of each textbook must be known, use identical textbooks if possible. (Your *Nelson Chemistry* textbook is 1540 g.)
- The books will have to be steadied by your hand, so this may introduce a slight amount of error.
- If you can, get a partner to help you.
- When reading volume measurements from the syringe, read the measurement from the leading (first) black band on the plunger. The example volume shown reads **41.0 mL**.



Materials

- 60 mL syringe (35 mL syringe or larger will do)
- retort stand
- utility clamps
- rubber stopper (No. 5 or larger)
- five identical books

Procedure

- Fill the syringe with air to the 40.0 mL mark.
- Set up the apparatus as shown in Figure 2.6. Support the syringe, so that the bottom end seals against the stopper. It is very important to get a good seal. You may find it necessary to make a small depression in the stopper to get a good seal.
- Double-check that the syringe is set at the 40.0 mL mark.

FIGURE 2.6: Boyle's Law Apparatus

- Prepare a table similar to the following for recording your evidence.

Number of Books	Volume (mL)
0	40.0
1	

- Add one book and read the volume. Record the value in your evidence table.

11. Complete the evidence for this investigation by adding books and recording volumes in your evidence table after each book until you have added all five books.

Analysis

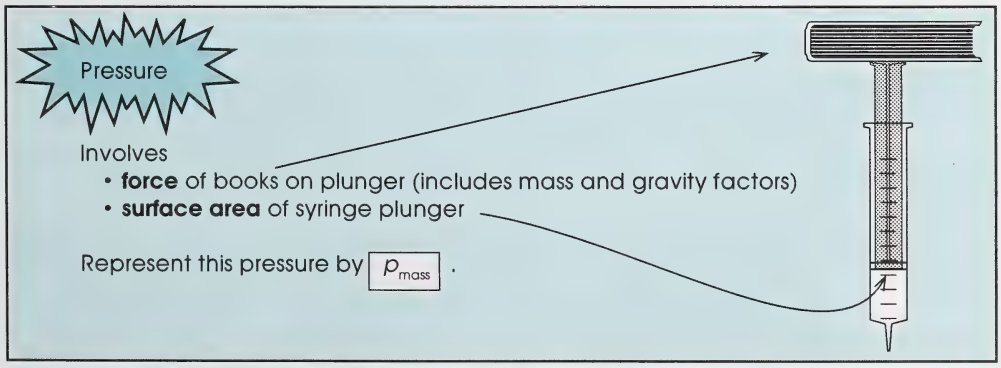
Answer the following questions as part of your analysis.

12. What happened to the volume of gas as the pressure increased?

13. Is the relationship between pressure and volume direct (both variables increase together) or indirect (as one variable increases, the other variable decreases)?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Part of your analysis that follows involves constructing a graph of pressure (manipulated variable) versus volume (responding variable). The different numbers of books gave you the different pressures required. However, the actual pressure on the air in the syringe involves not only the mass of the books, but the surface area of the plunger in the syringe pushing on the air as well.


Pressure
Involves
• force of books on plunger (includes mass and gravity factors)
• surface area of syringe plunger
Represent this pressure by p_{mass} .

You can calculate the force applied by the books as follows:

$$F_{books} = m_{books} \times g$$

where F = force applied by the books in Newtons (N)

m = mass of the books in kilograms (kg)

g = acceleration due to gravity (9.8 m/s^2)

Using the *Nelson Chemistry* textbook (1540 g or 1.540 kg) as an example, the force applied by one book is $F = m \times g$

$$= 1.540 \text{ kg} \times 9.8 \frac{\text{m}}{\text{s}^2}$$

$$= 15 \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \text{ or } 15 \text{ N}$$

The surface area of the syringe plunger is also important. Since the plunger is round, you need to use πr^2 to find the surface area.

For a 60 mL syringe, where r is the radius (1.25 cm or 0.0125 m), the surface area is as shown in Figure 2.7.

$$A = \pi r^2$$
$$= 3.14\ (0.0125 \text{ m})^2$$
$$= 4.91 \times 10^{-4} \text{ m}^2$$

FIGURE 2.7: Plunger Area

These two values, the force and the surface area, are used to get the pressure due to the books, p_{mass}, as shown in Figure 2.8.

Pressure is usually measured in kilopascals (kPa). Since $1 \text{ kPa} = 1000 \frac{\text{N}}{\text{m}^2}$, then

$3.1 \times 10^4 \frac{\text{N}}{\text{m}^2} = 3.1 \times 10^1$ kPa or 31 kPa. Therefore, the pressure due to each *Nelson Chemistry* textbook is 31 kPa.

$$p_{mass} = \frac{\text{force of books}}{\text{surface area}}$$
$$= \frac{15 \text{ N}}{4.91 \times 10^{-4} \text{ m}^2}$$
$$= 3.1 \times 10^4 \frac{\text{N}}{\text{m}^2}$$

FIGURE 2.8: Finding Pressure

Since there was air in the syringe when you started, that air was subjected to atmospheric pressure besides any pressure you created from the books. As you have already seen, atmospheric pressure, p_{atm}, is around 100 kPa. (This pressure can vary depending on where you live.) So, the total pressure on the air in the syringe, p_{total}, is due to the pressure made by the books and atmospheric pressure.

$$p_{total} = p_{atm} + p_{mass}$$

So, for one book,

$p_{total} = 100 \text{ kPa} + 31 \text{ kPa}$

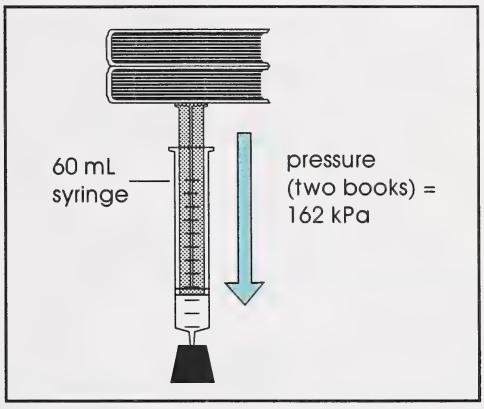
$= 131$ kPa

For two books,

$p_{total} = 100 \text{ kPa} + (31 + 31) \text{ kPa}$

$= 162$ kPa

If you are using *Nelson Chemistry* textbooks as your masses and a 60 mL syringe, you can use the following pressure values that have been supplied, along with an atmospheric pressure of 100 kPa. If you are using different equipment, or have a different atmospheric pressure where you are, you can find the total pressures by doing the calculations described previously.



14. a. Transfer your volume data to a table similar to the one given.

Number of Books	Total Pressure (kPa)	Syringe Volume (mL)
0	100	40.0
1	131	
2	162	
3	193	
4	224	
5	255	

b. Use graph paper to construct a graph of total pressure (manipulated variable) versus syringe volume (responding variable). Remember, the manipulated variable goes on the horizontal axis, and the responding variable goes on the vertical axis. Use an appropriate scale, and be sure to label your graph.

15. a. Transfer your total pressure and syringe volume values into a table similar to the one following. Complete the third column by multiplying each pair of data.

p (kPa)	v (mL)	$p \times v$ (kPa·mL)
100	40.0	4.00×10^3

b. What is the relationship (trend) between the product values in the right-hand column of the table?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Note: You may wish to try Part B as an alternate procedure for this investigation.

End of Part A

Part B

Purpose

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

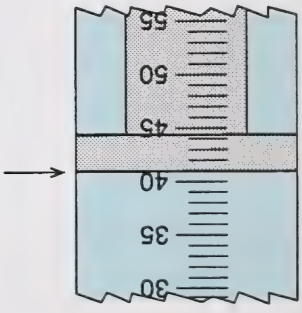
The purpose of this investigation is to determine the relationship between pressure and volume of a gas.

Design

A fixed quantity of air will be trapped in a syringe. Pressure on the plunger will be varied and the volume recorded.

Guidelines

- Use a bathroom scale to give mass data. If the scale reads in pounds, convert to kilograms using the conversion 2.2 lbs = 1 kg.
- If you can, get a partner to help you.
- When reading volume measurements from the syringe, read the measurement from the leading (first) black band on the plunger. The example volume shown reads **41.0 mL**.

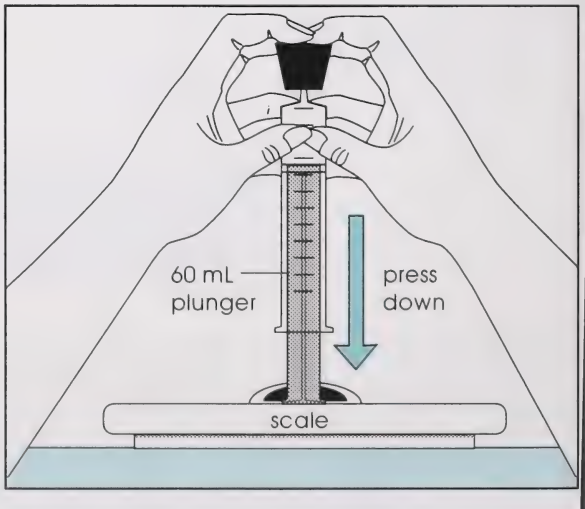


Materials

- 60 mL syringe (35 mL syringe or larger will do)
- household scale
- rubber stopper (No. 5 or larger)

You can set up the apparatus as shown in the diagram on the right.

If possible, set the bathroom scale on a table to make it easier for you to read the scale and syringe measurements.



Procedure

- Fill the syringe with air to the 40 mL mark.
- Set up the apparatus as shown in the preceding diagram.
- Press down on the stopper end of the syringe until the scale reads 2 kg.
- Read the volume measurement on the syringe.
- Reset the plunger to 40 mL.
- Press down until the scale reads 4 kg. Record the volume.
- Repeat this procedure for 6 kg, 8 kg, and 10 kg scale readings.

16. Record your evidence in a data table similar to the one given.

Mass on Scale (kg)	Syringe Volume (mL)
0	40.0
2	

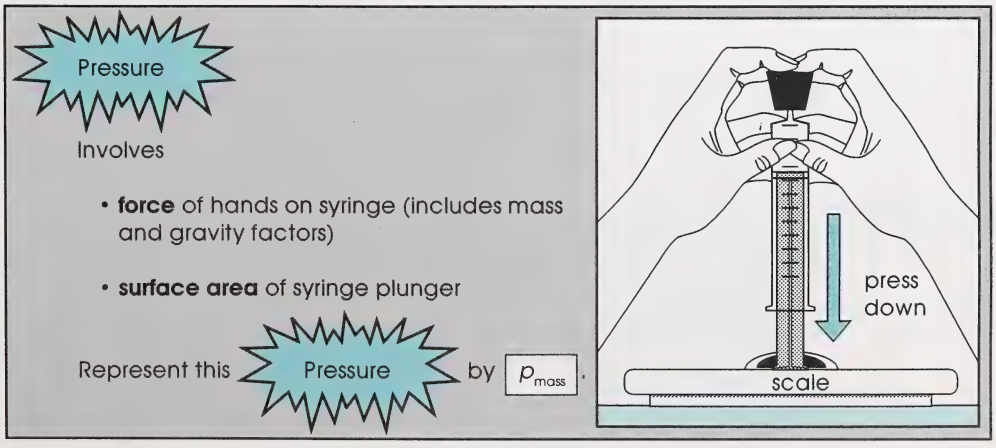
Analysis

Answer the following questions as part of your analysis.

17. What happened to the volume of gas as the pressure increased?

18. Is the relationship between pressure and volume direct (both variables increase together) or indirect (as one variable increases, the other variable decreases)?

Part of your analysis involves constructing a graph of pressure (manipulated variable) versus volume (responding variable). The pressure applied to the bathroom scale gave you the different pressure values required. However, the actual pressure on the air in the syringe involves not only the mass readings from the bathroom scale, but the surface area of the plunger in the syringe pushing on the air as well.



You can calculate the force applied on the syringe as follows:

$$F = m \times g$$

where F = force applied on the syringe in Newtons (N)

m = mass reading on scale in kilograms (kg)

g = acceleration due to gravity ($9.8\ m/s^2$)

If you use a 2.0 kg mass reading from the scale as an example, the force applied to give the 2.0 kg mass reading would be: $F = mg$

$$= 2.0\ kg \times 9.8 \frac{N}{m^2}$$

$$= 20 \frac{kg \cdot m}{s^2} \text{ or } 20\ N$$

The surface area of the syringe plunger is also important. Since the plunger is round, you need to use πr^2 to find the surface area.

For a 60 mL syringe, where r is the radius (1.25 cm or 0.0125 m), the surface area is as shown in Figure 2.9.

$$A = \pi r^2$$
$$= 3.14\ (0.0125\ m)^2$$
$$= 4.91 \times 10^{-4}\ m^2$$

FIGURE 2.9: Plunger Area

These two values, the force and the surface area, are used to get the pressure due to the hands on the syringe, p_{mass}, as shown in Figure 2.10.

Pressure is usually measured in kilopascals (kPa). Since $1\ kPa = 1000 \frac{N}{m^2}$, then

$4.1 \times 10^4 \frac{N}{m^2} = 4.1 \times 10^1$ kPa or 41 kPa. Therefore, the pressure due to each 2.0 kg scale reading is 41 kPa.

$$P_{mass} = \frac{\text{force on syringe}}{\text{surface area}}$$
$$= \frac{20\ N}{4.91 \times 10^{-4}\ m^2}$$
$$= 4.1 \times 10^4 \frac{N}{m^2}$$

FIGURE 2.10: Finding Pressure

Since there was air in the syringe when you started, that air was subjected to atmospheric pressure besides any pressure you created from your hands on the syringe. As you have already seen, atmospheric pressure, p_{atm}, is around 100 kPa. (This pressure can vary depending on where you live.) So, the total pressure on the air in the syringe, p_{total} is due to the pressure made by your hands and atmospheric pressure.

$$p_{total} = p_{atm} + p_{mass}$$

So, for a 2.0 kg scale reading,

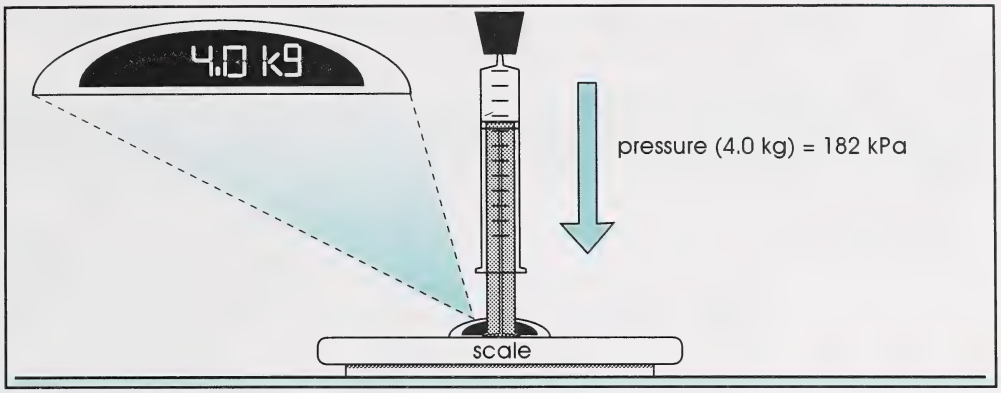
$p_{total} = 100\ kPa + 41\ kPa$

$= 141\ kPa$

For a 4.0 kg scale reading,

$p_{total} = 100\ kPa + (41 + 41)\ kPa$

$= 182\ kPa$



If you use the suggested bathroom scale values given, the pressures are already calculated for you and listed in the table in the following question.

19. Transfer your syringe volumes to a table similar to the one given.

Scale Mass (kg)	Total Pressure (kPa)	Syringe Volume (mL)
0	100	40.0
2	141	
4	182	
6	223	
8	264	
10	305	

20. Use graph paper to construct a graph of total pressure (manipulated variable) versus syringe volume (responding variable).

Remember, the manipulated variable goes on the horizontal axis, and the responding variable goes on the vertical axis. Use an appropriate scale, and be sure to label your graph.

21. a. Transfer your total pressure and syringe volume values into a table similar to the one following. Complete the third column by multiplying each pair of values.

p (kPa)	v (mL)	$p \times v$ (kPa•mL)
100	40.0	4.00×10^3

b. What is the relationship (trend) between the product values in the right-hand column of the table?

Check your answers by turning to the Appendix, Section 2: Activity 2.

End of Part B

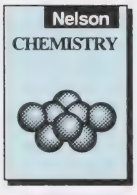
22. From your results in the investigation in Part A or Part B, state the relationship between pressure and volume of a confined gas.

23. a. How does the mass of gas in the syringe vary throughout either experiment?

b. What kind of variable is the mass of gas?

Check your answers by turning to the Appendix, Section 2: Activity 2.

You have had the opportunity to develop a relationship between pressure and volume of a gas using your own evidence in an investigation.



To further confirm the relationship between pressure and volume of a gas, turn to page 144 of your textbook and complete Lab Exercise 6A: Pressure and Volume of a Gas. Perform the analysis required by answering the following five questions.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

24. Use graph paper to construct a graph of pressure versus volume. Use the values given in your textbook. Remember, the manipulated variable goes on the horizontal axis, and the responding variable goes on the vertical axis.

25. Is the relationship between pressure and volume direct or indirect?

26. a. Multiply the pressure times the volume for each of the five measurements in the Evidence Table. Then fill in all the values in a table similar to the one following. The first value is done for you.

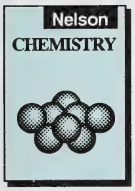
Pressure (kPa)	Volume (L)	$p \times v$ (kPa·L)
100	5.00	500

b. What is the relationship between the five products?

27. Do the results from Lab Exercise 6A support the results of the preceding investigations in Part A and Part B regarding the relationship between the pressure and volume of a confined gas? Explain.

28. It is stated in Lab Exercise 6A that temperature and the amount of gas are controlled variables in the experiment. Why must they be kept constant?

Check your answers by turning to the Appendix, Section 2: Activity 2.

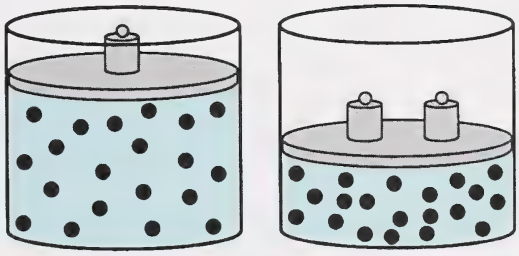


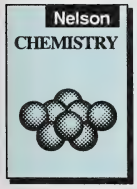
Review the bottom half of page 150 and the top of page 151 of your textbook to answer the next question on Boyle's law.

29. How does the kinetic molecular theory explain Boyle's law?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Boyle's law can also be explained by saying that as pressure increases, the molecules are forced closer together, which decreases the volume. More collisions with the container walls occur.





Your evidence from the previous investigation should support Boyle's law which states that if temperature and amount (moles) are controlled (kept constant), $p \times v$ = a constant, or $p \times v$ = the same number. Read from the bottom of page 144 to the middle of page 145 in your textbook to see how Boyle's law is expressed.

30. State Boyle's law in equation form.

31. What other inverse relationship did you study in Module 1?

The following example illustrates how Boyle's law is used to solve problems involving only changes of pressure and volume (Temperature and moles must be controlled.).

If 5.00 L of a gas at 87 kPa is exposed to 130 kPa, what is the new volume of the gas?

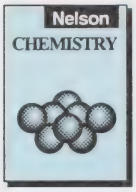
$$p_1v_1 = p_2v_2$$

$$87 \text{ kPa} \times 5.00 \text{ L} = 130 \text{ kPa} \times v_2$$

$$\frac{87 \text{ kPa } (5.00 \text{ L})}{130 \text{ kPa}} = v_2$$

$$3.35 \text{ L} = v_2$$

As you can see, when exposed to the higher pressure, the volume of the sample decreases.



32. Complete question 3 of the exercise on page 149 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 2.

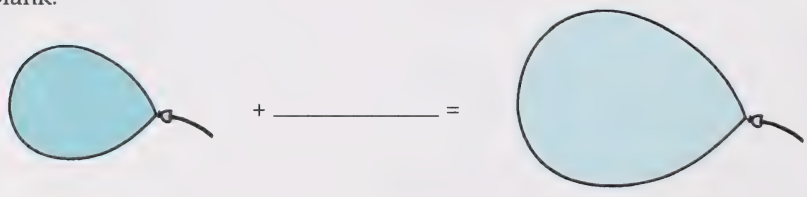
You have just taken a close look at pressure. You now know why water pumps and straws work. The relationship between pressure and volume was also examined, and you should more clearly appreciate the danger a scuba diver faces. In the next activity you will look at a second variable that affects the volume of a gas.

ACTIVITY 3

Charles' Law

Do you like popcorn? Almost everyone does. Do you know how that hard little kernel of corn turns into a soft tasty treat? The following question will give you a hint.

1. What is needed to make a small tied balloon into a large tied balloon? Fill in the blank.



You may have said more air, but because the balloon is tied, no more air can be added. So what is the answer? Add some heat! That will make the balloon bigger.

The gas inside a hot kernel of popping corn is water vapour. When the pressure of the water vapour in the popcorn kernel gets up to about 900 kPa, the husk explodes and the kernel expands to thirty times its original volume. Now you have a snack!

Apply your new-found knowledge of the effect of heat on gas volume to the following question.

2. How is the fact that heated gases expand important to the following?

   a. a hot air balloonist
   b. an explosives expert
   c. a vulture
   d. a car engine technician

Check your answers by turning to the Appendix, Section 2: Activity 3.

Many people and animals depend on the way gases behave when they are heated. To understand the behaviour of heated gases, you must understand the relationship between temperature and **kinetic energy**.

kinetic energy – energy associated with motion

Read the bottom half of page 145 of your textbook to discover this relationship. Then do the following questions.

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3. Correct the following statements.

   a. In a gas sample at 20°C, all the particles have the same kinetic energy.

   b. In a cold sample of gas, no particles have high kinetic energies.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Can you think of any other relationships like the one between kinetic energy and temperature?

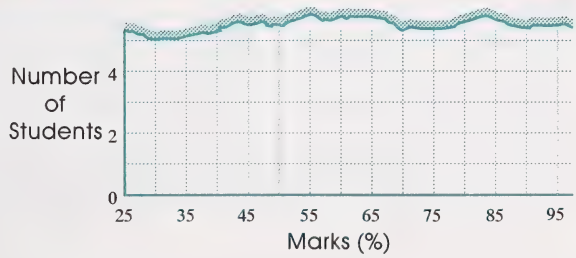
The machine that mixes the balls for a Bingo game illustrates the behaviour of gas particles. Some of the balls really move! Others sit still until they are hit – then they move. There are a large number of kinetic energies in a ball-mixing machine.

Analyse the following information to help you get a better understanding of the relationship between kinetic energy and temperature.

4. You are in a class of thirty students. The average mark in the class is 65%. There are a few students with low marks and a few students with high marks, but most students have marks close to the average. The mark distribution looks like this.

Mark (%)	35	45	55	65	75	85	95
Number of Students	1	3	6	10	6	3	1

Plot the information from the preceding chart onto a graph similar to the one shown here.



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Refer to Figure 6.3 on the bottom of page 145 of your textbook. Answer the following questions.

5. How does the shape of the line on your graph compare to the shape of the kinetic energy distribution shown in Figure 6.3?

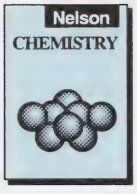
6. How are the marks of the students in the class similar to the kinetic energies of the particles in the sample?

7. As Figure 6.3 suggests, temperature is an indication of the average kinetic energy of a system of particles. What is it that indicates the average performance of students in a classroom?

8. Sketch a curve on the graph (showing mark distribution) you constructed that would represent the marks of the class if all the students studied harder.

9. Examine Figure 6.3 to see what happens to the kinetic energy of particles of a higher temperature. How does this compare to your answer to the preceding question?

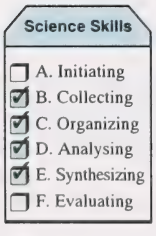
Check your answers by turning to the Appendix, Section 2: Activity 3.



The quantitative relationship between temperature and volume was discovered by Jacques Charles. He became interested in the relationship at a time when people in France were trying to develop balloons as flying machines. A picture of Jacques Charles can be seen in the margin on page 146 of your textbook.

Do the following investigation to verify the relationship called Charles' law.

Investigation: The Effect of Temperature on the Volume of a Gas (Charles' Law)



In this investigation you will be changing the temperature of a confined gas and measuring the volume. While performing the investigation, pay special attention to the required components, safety aspects, and applied science skills.

Purpose

The purpose of this investigation is to discover the relationship between temperature and volume of a gas.

Design

A sample of air trapped in a syringe will be exposed to ice water, room temperature, and boiling water. Various temperatures and volumes will be recorded.

Materials

- 60 mL syringe (or 35 mL syringe)
- thermometer
- 600 mL beaker
- rubber stopper
- hot plate (or equivalent)
- ice
- water
- retort stand and clamps

Procedure

- Construct a cap for the syringe tip using the rubber stopper. You will have to make a small hole or depression in the stopper to fit over the syringe tip.
- Remove the cap of the syringe and fill to the 20 mL mark with air. Replace the cap and record the syringe volume and room temperature.
- Prepare an ice bath in the 600 mL beaker (or another container). Measure the temperature until it gets to 0°C.
- Immerse the syringe and measure and record the lowest volume of gas in the syringe.
- Set up the apparatus as shown in Figure 2.11. (**Note:** If you don't have lab facilities, this portion of the experiment can be done in a saucepan on the stove. In one hand hold the syringe with a pair of tongs. Hold the thermometer in your other hand.)
- Gradually heat the water. Record the volume of gas in the syringe at 40°C, 60°C, 80°C, and the temperature at which the water boils.

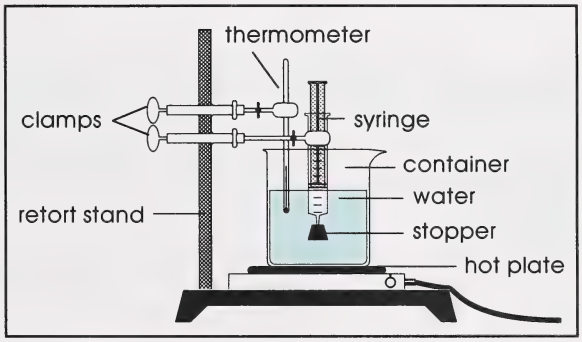


FIGURE 2.11: Charles' Law Apparatus

10. Record your evidence in a data table similar to the following:

Temperature (°C)	Volume (mL)
0.0	
Room temperature _____	20.0
40.0	
60.0	
80.0	
Boiling water _____	

Answer the following questions to complete your analysis.

11. On graph paper, draw a graph of temperature versus volume. Remember, the manipulated variable goes on the horizontal axis, and the responding variable goes on the vertical axis.

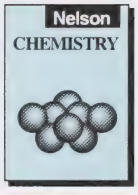
12. a. What happens to the volume as the temperature of a gas is increased?

    b. Is the relationship between temperature and volume direct or indirect?

13. Calculate the values for $\frac{v}{T}$ for each of the measurements in your data table in question 10. Record them in a chart similar to the one following. An example is shown for a room temperature of 20°C.

Temperature (°C)	Volume (mL)	$\frac{v}{T}\left(\frac{\text{mL}}{\text{°C}}\right)$
Room temperature – 20.0	20.0	1.00

14. Do you find a constant relationship for $\frac{v}{T}\left(\frac{\text{mL}}{\text{°C}}\right)$?



You have found that $\frac{v}{T}\left(\frac{\text{mL}}{\text{°C}}\right)$ does not give a constant number. To see the reason why, read the section Kelvin Temperature scale on pages 146 to 148 of your textbook. This section will help you see how the Kelvin temperature scale assists in finding the regularity that is Charles' law.

15. How do you convert degrees Celsius to kelvin? Give an example.

Kelvin – a temperature scale in which water freezes at 273°C and boils at 373°C

16. Complete the chart.

Unit	°C	K
Standard ambient temperature		
Freezing point of water		
Coldest temperature possible		
Body temperature	37	

17. Which of the following illustrations best represents the comparison of the sizes of the Celsius degree and a degree in the Kelvin scale?

A

B

C

Check your answers by turning to the Appendix, Section 2: Activity 3.

Now that you can convert degrees Celsius to kelvin, complete the following questions about the Charles' law investigation you performed earlier.

18. a. Convert the Celsius temperatures you recorded in question 13 to Kelvin and put them into a table similar to the following one given.

Temperature (°C)	Temperature (K)
0.0	273.0

b. Now use the kelvin values from your table to calculate ratios of $\frac{v}{T}\frac{(\text{mL})}{(\text{K})}$ using the volumes recorded in question 13. Make a third column in a table to record these ratios as shown.

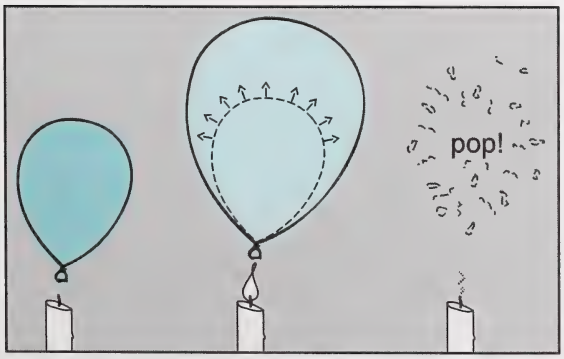
Temperature (K)	Volume (mL)	$\frac{v}{T}\frac{(\text{mL})}{(\text{K})}$
273.0	18.6	0.0681

19. Is $\frac{v}{T}$ a constant number when temperature is measured in kelvin?

20. State Charles' law of gases.

21. Why must pressure and the amount (moles) of gas be kept constant in the investigation?

Check your answers by turning to the Appendix, Section 2: Activity 3.



Charles' law is used to calculate changes in volume or temperature (in kelvin) of gas samples where pressure and amount are controlled (kept constant).

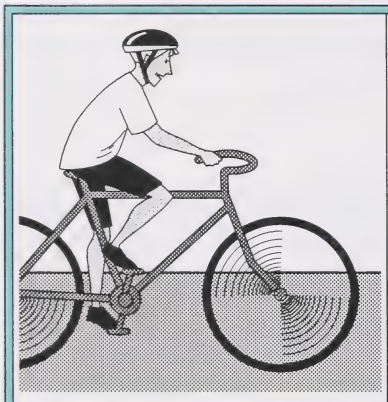
If a 15.0 L sample of a gas at standard ambient temperature is heated to 75.0°C, what is the new volume? (standard ambient temperature = 25.0°C)

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

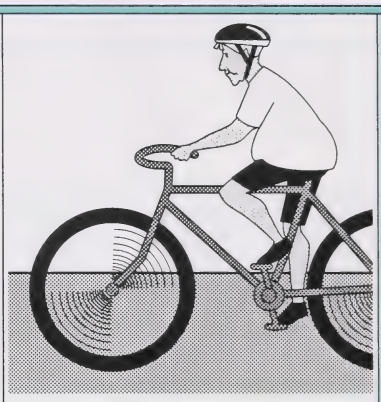
$$\frac{15.0\ \text{L}}{(25+273)\ \text{K}} = \frac{V_2}{(75+273)\ \text{K}}$$

$$V_2 = \frac{15.0\ \text{L} \times 348\ \text{K}}{298\ \text{K}} = 17.5\ \text{L}$$

When the temperature increased from 25.0°C to 75.0°C, the volume increased from 15.0 L to 17.5 L.



Going to the Candy Store



Coming Back

When a bike has been ridden a long way, the tires heat up. This actually causes the volume of the tires to increase.

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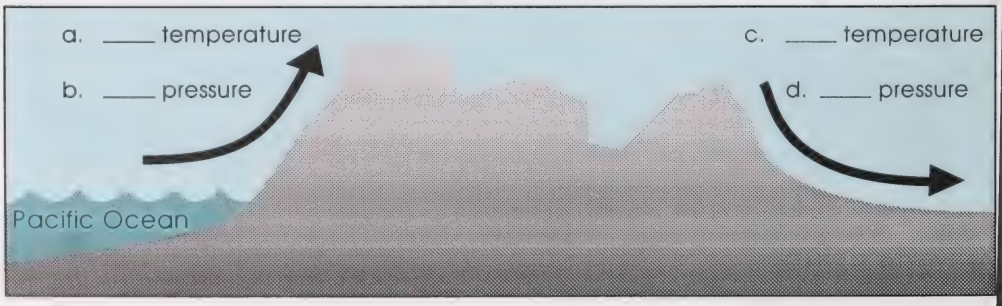
22. Do question 1 on page 149 of your textbook to make sure you can apply Charles' law.

The right margin of page 149 in your textbook illustrates two good examples of how the gas laws affect your life. Read these examples; then answer the following questions.

23. The following diagram depicts air from the Pacific Ocean going from west to east over the Rocky Mountains. Redraw the diagram on your own paper and indicate by arrows whether the temperature and the pressure are increasing (↑) or decreasing (↓) on either side of the mountains.



24. Indicate which law, Boyle's or Charles', explains why baked goods are light and fluffy.

Check your answers by turning to the Appendix, Section 2: Activity 3.

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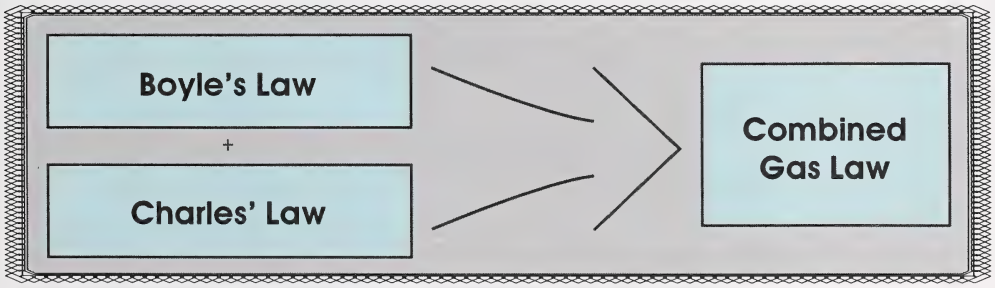
You have already seen how the kinetic molecular theory helps to explain the behaviour of gases. Review the sections on page 150 and the top of page 151.

25. How does the kinetic molecular theory explain Charles' law?

26. Do question 10 (a-d) on page 153 and 154 of your textbook.

Boyle's law is only useful when temperature is kept constant, and Charles' law only works when pressure is controlled. In most research dealing with gases in a lab situation, no attempt is made to keep either pressure or temperature constant. Read The Combined Gas Law on pages 148 and 149 of your textbook to see how calculations can be done under the conditions of changing temperature and pressure. Work through the example given on page 149.



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27. Use the combined gas law to solve questions 4, 5, and 7 on page 150 of your textbook. For question 7, assume the temperature does change from 30°C to SATP temperature conditions.

You have seen that gases easily compress and expand in response to changes in both pressure and temperature. Boyle's law and Charles' law allow you to predict quantitatively what the changes in gas volume will be.

28. To review some of the concepts of Activity 3, do questions 1, 14, 16, and 17 on pages 161 and 162 of *Nelson Chemistry*.

Check your answers by turning to the Appendix, Section 2: Activity 3.

You have examined the relationship between pressure, temperature, and volume using Boyle's law and Charles' law. The mysteries of the popping corn and the expanding balloon are now solved. In the next activity you will see how the amount of a gas also affects volume and how the gas laws are responsible for the beginning of Chemistry as a science.

ACTIVITY

4 Avogadro's Idea

Have you ever seen hot air balloonists use large fans to fill their balloons for takeoff? Thousands of litres of air are blown in, and as the air goes in, the balloon inflates.

If you have ever blown up a party balloon, or an air mattress, or your bicycle tire, you have done the same thing as the hot air balloonist. All these objects are blown up with air. Is air the only gas used to inflate things?

COURTESY OF AERO DYNAMICS

1. List which of the following gases would be found in each inflated object given: $N_{2(g)}$, $O_{2(g)}$, $CO_{2(g)}$, $H_2O_{(g)}$, $He_{(g)}$.

   a. hot air balloon

   b. balloon filled from a cylinder (If you don't hold on to it, it will float away.)

   c. balloon blown up by mouth

   d. self-inflating lifeboat

Many types of gases are used to inflate objects, but is there a best gas with which to fill them? Is there a secret formula gas? Will oxygen give you more volume per molecule than nitrogen? The answers to these questions, and the ways in which the answers are determined, give an excellent illustration of how science progresses.

The subject of this activity is the new theory of Avogadro, which is mentioned in Figure 2.12.

FIGURE 2.12: An Example of the Development of Scientific Knowledge

To see how Avogadro came upon his theory, consider the steps of the process represented in Figure 2.12 by watching three video segments and working through the following materials.

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The old theory, as represented in Figure 2.12, is based on a theory you may remember from Science 10 – Dalton's atomic theory. John Dalton was the first modern scientist to depict matter as tiny atoms. His theory is summarized on page 57 of your textbook. Read page 57 to review Dalton's atomic theory, and then consider the following inferences.

Dalton made several inferences (conclusions) based on his experiments with gases and his atomic theory. Three of his conclusions are listed next.

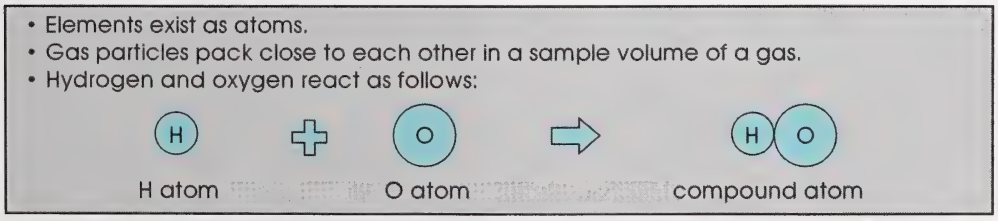

• Elements exist as atoms.
• Gas particles pack close to each other in a sample volume of a gas.
• Hydrogen and oxygen react as follows:
H
O
H O
H atom
O atom
compound atom

FIGURE 2.13: Dalton's Inferences

How did Dalton come to these conclusions?

View video segment 2, Gas Volumes, of *The Mole Concept Series* to see a similar reasoning process to what Dalton used. Then answer the following questions to confirm your understanding. You may find it helpful to read through the questions before watching the video.

2. What physical evidence can be used to refute Dalton's idea that gas molecules pack close together?

3. a. What factor is more important than the size of gas particles in determining the number of gas particles that fit in a container?

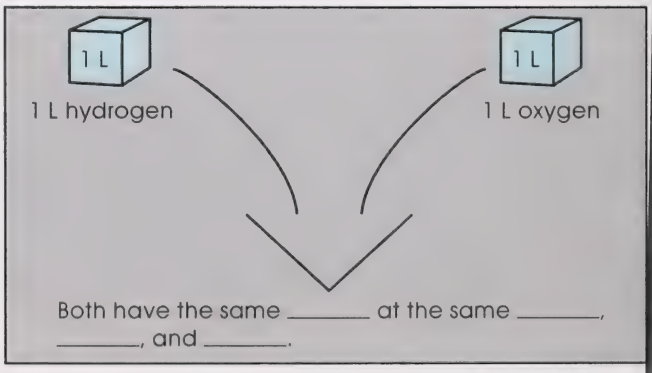
   b. What variables can affect this factor?

FIGURE 2.14: John Dalton BETTMANN ARCHIVE

4. Match the variables that must be controlled (for the universal particle container to work) to the way it was represented in the concert hall analogy.

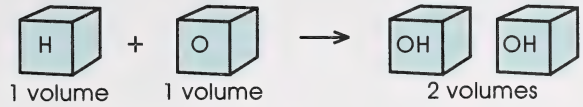
a. temperature	i. size of hall
b. volume	ii. rubbing elbows
c. pressure	iii. hot or cold people

5. Fill in the blanks.



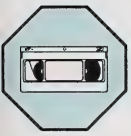
Check your answers by turning to the Appendix, Section 2: Activity 4.

Dalton felt that since atoms were close together, forming *compound atoms* (his words for molecules) should not greatly affect the amount of space they occupy. He predicted that the volume of hydrogen (H) + volume of oxygen (O) = volume of the combined atom (OH).



As you have seen already, experimental evidence does not back Dalton's claim.

Joseph Gay-Lussac was a French chemist working on the reactions of gases. He published his law of combining volumes shortly after Dalton proposed his atomic theory. Gay-Lussac presented evidence that conflicted with Dalton's ideas.



To see the development process behind Gay-Lussac's law, view video segment 3, Combining Gas Volumes, of *The Mole Concept Series*. Preview the following questions before viewing the video.

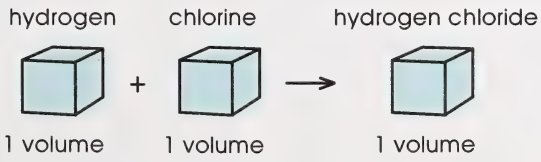
6. How many creatures in a bag would you have to draw to represent these molecules? Match the numbers to the correct molecules.

   a. CH_4 i. three

   b. NH_3 ii. four

   c. CO_2 iii. five

7. The earlier part of the video Combining Gas Volumes suggests, as Dalton might, the following:



   Rewrite or redraw this concept to reflect the evidence that Gay-Lussac discovered.

8. Fill in the blanks to further reflect Gay-Lussac's evidence.

   a. ___ volume(s) hydrogen + ___ volume(s) oxygen → ___ volume(s) water

   b. ___ volume(s) hydrogen + ___ volume(s) nitrogen → ___ volume(s) ammonia

9. Balance the following equations by filling in the blanks.

   a. $\_\_ H_{2(g)} + \_\_ O_{2(g)} \rightarrow \_\_ H_2O_{(g)}$

   b. $\_\_ H_{2(g)} + \_\_ Cl_{2(g)} \rightarrow \_\_ HCl_{(g)}$

   c. $\_\_ H_{2(g)} + \_\_ N_{2(g)} \rightarrow \_\_ NH_{3(g)}$

Note: It is not necessary to write the coefficient if it is 1. The coefficient 1 is assumed for substances in balanced equations that have no other coefficient.

10. How do the volumes in question 7 compare with the balancing coefficients in question 9. b.?

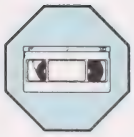
11. State Gay-Lussac's law of combining volumes.

12. Keeping in mind that Dalton thought that atoms of a gas were close together, predict what volumes he would have assumed would form from these reactions.

Reaction	Gay-Lussac's Determination	Dalton's Prediction
$1\ L\ N_2 + 3\ L\ H_2 \rightarrow$	$2\ L\ NH_3$	$\_\_ L\ NH_3$
$1\ L\ H_2 + 1\ L\ Cl_2 \rightarrow$	$2\ L\ HCl$	$\_\_ L\ HCl$
$2\ L\ H_2 + 1\ L\ O_2 \rightarrow$	$2\ L\ H_2O$	$\_\_ L\ H_2O$

Check your answers by turning to the Appendix, Section 2: Activity 4.

You have seen that the volumes predicted by Dalton are not the same as Gay-Lussac's determinations. It is at this point, when a theory fails, that scientists should re-evaluate their views of reality. Dalton didn't, but Avogadro did.



Avogadro's explanation of Gay-Lussac's conflicting evidence was very creative. It required that he think about matter in a completely new way. View video segment 4, Avogadro's Hypothesis, of *The Mole Concept Series* to see Avogadro's explanation. Read through the following questions before watching the video.

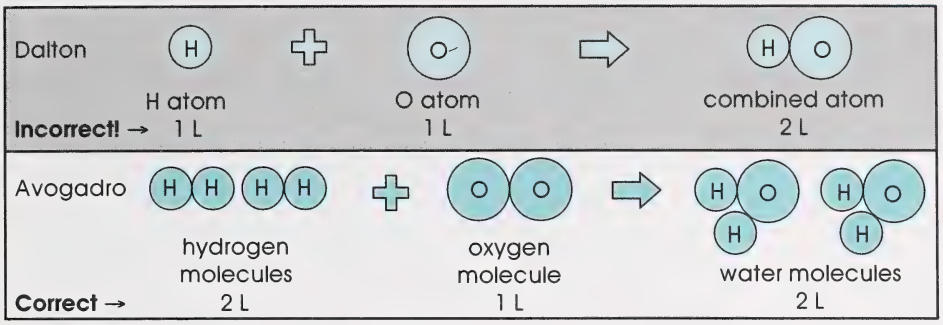
13. State the flaw in each of the following theories presented in the Avogadro's Hypothesis video.

    a. Suspicious Meat Theory

    b. Bigger Burger Theory

    c. Crooked Cook Theory

14. State Avogadro's hypothesis (which is now considered Avogadro's theory).



15. What new concept about the elements did Avogadro introduce to help him explain the law of combining volumes?

16. What is the relationship between the number of molecules present and the volume of each gas present in Avogadro's solution?

17. Where did the search for the smallest gas particle end – the atom or the molecule?

Check your answers by turning to the Appendix, Section 2: Activity 4.

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Both Gay-Lussac's law and Avogadro's theory are described in your textbook on page 151 and the top half of page 152. Read this section paying attention to the margin notes and the example given.

18. Apply Avogadro's theory to the following problem. If 20 L of SO_2 react with 10 L of O_2 at SATP, how many litres of SO_3 will form at SATP according to the following balanced reaction?

$$2\,SO_{2(g)} + O_{2(g)} \rightarrow 2\,SO_{3(g)}$$

19. Is there really a secret formula gas, as mentioned at the start of this activity, that gives you more volume per molecule ?

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20. Avogadro's theory has many applications in everyday life. Do question 19 (a,b) on page 162 of your textbook to see how Avogadro's hypothesis applies to a domestic situation.

Check your answers by turning to the Appendix, Section 2: Activity 4.

Avogadro's hypothesis was very important in developing the kinetic molecular model. However, like many other good scientific theories, Avogadro's was not accepted for a long time. This is quite common in science.

21. Name one other important theory you know about that wasn't accepted until long after it was put forth.

22. Identify the statements that may explain why Avogadro's theory was not immediately accepted.

    a. Berzelius, who was a prominent chemist of the day, would not accept Avogadro's hypothesis.

    b. Avogadro's hypothesis explained the law of combining volumes very well.

    c. The behaviour of some gases didn't fit with Avogadro's hypothesis.

    d. Avogadro was not well-educated.

Check your answers by turning to the Appendix, Section 2: Activity 4.

It isn't only the search for truth that influences the advancement of science, as you can see from Avogadro's theory and other good theories you may have suggested that weren't immediately accepted. Avogadro's theory was, however, finally accepted, and it explains the last gas law – Avogadro's law.

The following chart contains some experimental measurements that were taken on a sample of gas. Use this information to help you determine Avogadro's law.

Moles of Gas (*n*) (mol)	Volume (*v*) (L)
0.12	2.9
0.38	9.4
0.56	13.9
0.78	19.3
1.26	31.2

23. a. Draw a graph of moles of gas versus volume for the preceding measurements. Use graph paper for your answer.

    b. Is the relationship between the variables direct or indirect? Explain.

24. a. Complete the chart by calculating values for $\frac{v}{n}$ for each of the measurements.

Moles (mol)	Volume (L)	$\frac{v}{n}\left(\frac{\text{L}}{\text{mol}}\right)$
0.12	2.9	
0.38	9.4	
0.56	13.9	
0.78	19.3	
1.26	31.2	

b. Analysing the results in your chart, what is Avogadro's law?

25. Why do temperature and pressure need to be controlled when using Avogadro's law for solving problems?

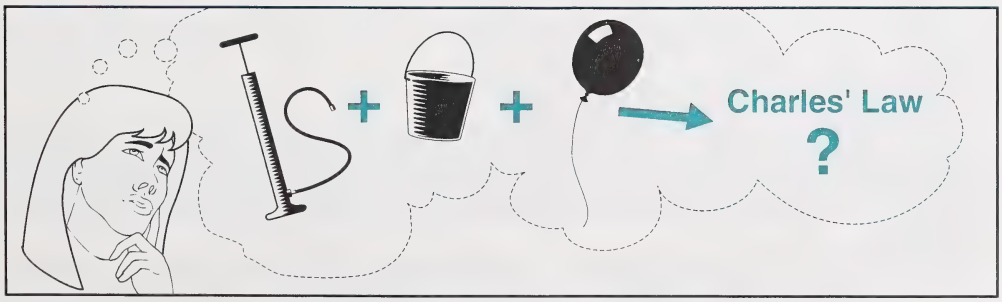
26. If 11.6 mol of a gas takes up 35.8 L, how many moles will fill up 7.6 L?

Check your answers by turning to the Appendix, Section 2: Activity 4.

You have seen how the three gas laws were developed by using careful experimental procedures and by keeping controlled variables constant. You have also seen how the kinetic molecular theory was developed through clear thinking and creative leaps of insights by men such as Dalton, Gay-Lussac, and Avogadro. In the next activity you will get the chance to verify one of the gas laws using materials you have at home.

ACTIVITY

5 Verifying the Gas Laws



Did you ever think that your bicycle pump could be used for more than just pumping up tires? How can a balloon and a pail help to verify Charles' law?

In this activity you will get a chance to practise good science by first designing your own experiment, and then carrying out the experiment to verify one of the gas laws. The experiment you will perform is based on a question in your textbook.

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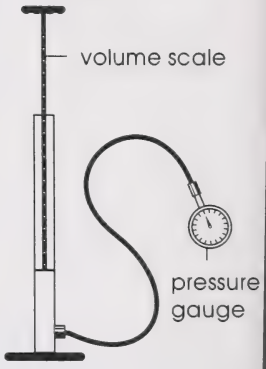
First read question 31 on page 163 of *Nelson Chemistry* to get an idea of what is involved in the experiment. Before writing your design, consider the following hints:

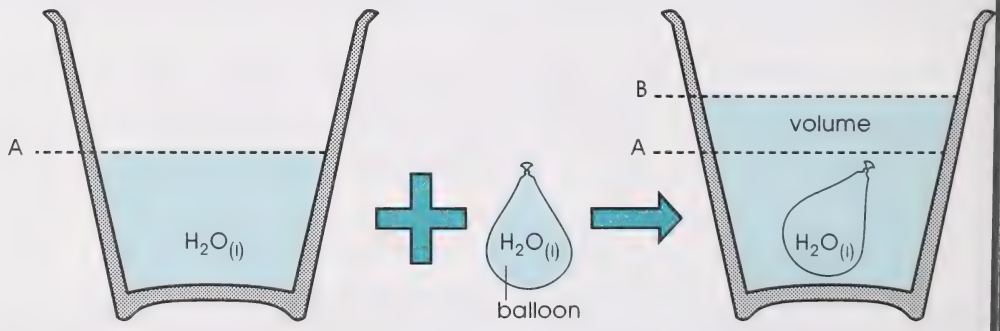
Science Skills

- [x] A. Initiating
- [ ] B. Collecting
- [ ] C. Organizing
- [ ] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

- Design an experiment that tests either Boyle's law or Avogadro's law.
- The pressure gauge fits onto the bicycle pump. The volume in the bicycle pump can be read from a scale on the plunger as shown in the following illustration.



- The pump can also make a seal with the balloon. Each time the handle goes up and down, the same mass of gas is put into the balloon.
- The balloon can be submerged in the bucket to see how much water is displaced. The following graphic shows a water-filled balloon to illustrate the concept.



- The changed volume in the pail can be measured with the measuring cup by adding water until you get from A to B (as shown in the preceding illustration).

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1. Complete textbook question 31 on page 163 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 5.

Do the following question about the things you would need to consider if you actually carried out your design.

2. What calculation would you do with the data you collected from your experiment to see if the law was verified?

Law	Manipulated Variable	Responding Variable	Controlled Variable
Boyle	p	v	n, T
Charles	T	v	n, p
Avogadro	n	v	p, T

You have just written a design for an experiment. The mental processes and techniques you used to develop your design exhibit good science. The following investigation will allow you to put your design ideas to good use.

Investigation: Verifying Charles' Law

Science Skills

- ☑ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

Purpose

The purpose of this investigation is to test Charles' law.

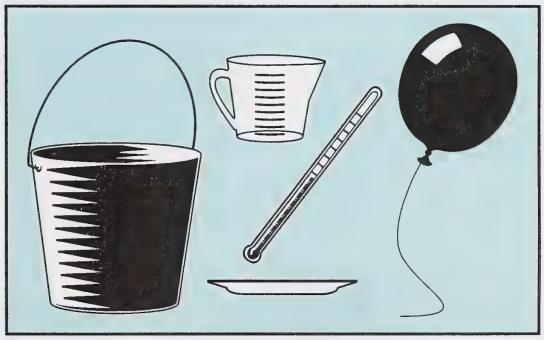
Guidelines

- Charles' law has been chosen so that a pump and pressure gauge are not required.
- You will be given some hints throughout the activity.
- While performing this investigation, pay special attention to the required components, safety aspects, and applied science skills.

3. Write a brief description of your design.

Materials

- pail
- hot water
- cold water
- balloon
- plate
- measuring cup
- alcohol thermometer



4. List the steps in your procedure.

Check your answers by turning to the Appendix, Section 2: Activity 5.

5. Record your evidence in a data table similar to the one following:

Temperature (°C)	Volume of Water Displaced by Balloon	Volume of Balloon

6. On graph paper, draw a graph of your manipulated variable versus your responding variable.

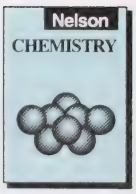
7. Do whatever calculation is necessary to find the quantitative regularity that represents Charles' law.

8. a. What sources of error did you have in your experiment?

   b. How could the errors be minimized with better equipment?

Check your answers by turning to the Appendix, Section 2: Activity 5.

Looking at the gas laws has given you an opportunity to study a good example of the process by which the amount of scientific knowledge increases. You have discovered how some scientists meet the challenge of new information, while others sometimes dodge the challenge. You also have been given an opportunity to become a better scientist yourself by designing and doing your own investigations.



9. Turn to page 161 in your textbook and complete questions 5 and 6.

Check your answers by turning to the Appendix, Section 2: Activity 5.

Practising good science is sometimes harder than it looks. The many advances you have seen in the world are an indication that good science is alive and well.

ACTIVITY 6

The Ideal Gas Law

How would you describe yourself?

There are so many different descriptions you could use! It is not the same with gases, though. You only need to say four things about a confined gas to completely describe it.

1. How would you completely describe a gas sample?

Check your answers by turning to the Appendix, Section 2: Activity 6.

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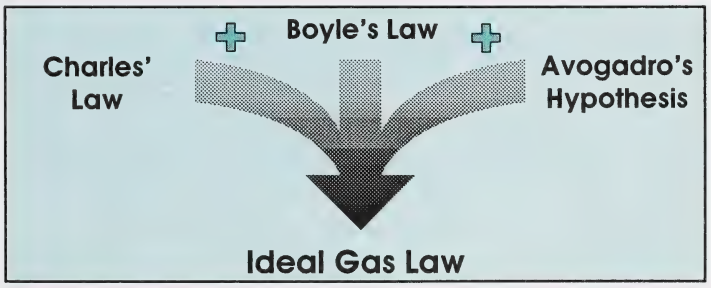
You may remember that gases are the simplest type of matter because of the great independence of the particles that make up gases. A gas can be completely described by the ideal gas law. Read page 158 and the top half of page 159 of your textbook to see what the ideal gas law is and how it comes from the three gas laws you have worked with already. Then answer the questions that follow.



2. a. What is the ideal gas law?

   b. What does the "*R*" stand for?

3. Calculate the volume of one mole of a gas under SATP conditions.

Check your answers by turning to the Appendix, Section 2: Activity 6.

All of the gas laws you have worked with so far can be derived from the ideal gas law.

Assume you have a question requiring Boyle's law. The p and v variables have changed, but n and T are controlled.

Initial Condition

$$p_1V_1 = n_1RT_1$$

Final Condition

$$p_2V_2 = n_2RT_2$$

Since $n_1 = n_2$ (controlled) and

$$n_1 = \frac{p_1V_1}{RT_1}, \qquad n_2 = \frac{p_2V_2}{RT_2}$$

then $\frac{p_1V_1}{RT_1} = \frac{p_2V_2}{RT_2}$.

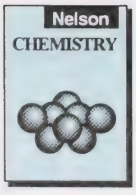
Since the Rs are the same, they cancel, leaving $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$.

Since T is controlled, $(T_1 = T_2)$, then $p_1V_1 = p_2V_2$ (Boyle's law).

4. If T and v change in a problem, and pressure and the number of moles are controlled, derive Charles' law. (Use similar methods to those shown previously.)

Check your answers by turning to the Appendix, Section 2: Activity 6.

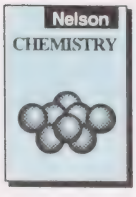
The ideal gas law allows you to solve any gas problem involving calculations.



5. Turn to page 159 of your textbook and do questions 24 and 25.

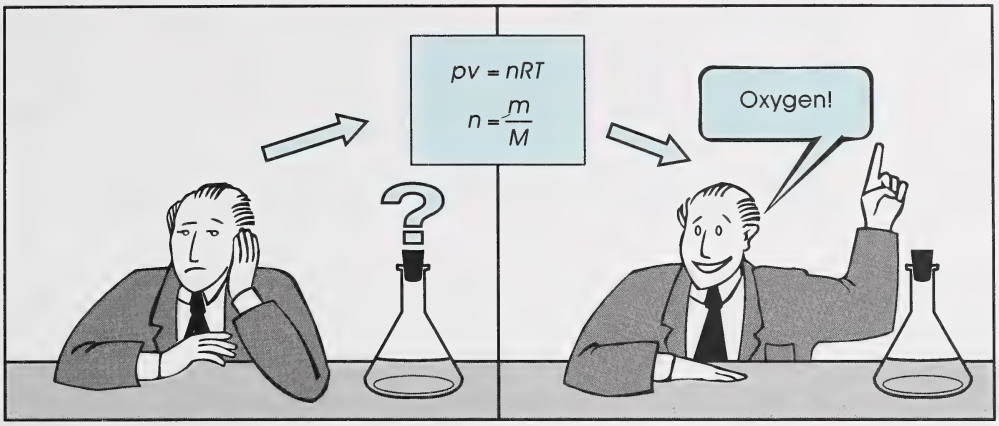
Check your answers by turning to the Appendix, Section 2: Activity 6.

Now that you have tried a few questions and checked your answers, try a few different variations of the ideal gas law by answering the following questions.



6. Turn to page 162 in your textbook and answer questions 10 and 11.

Check your answers by turning to the Appendix, Section 2: Activity 6.



You can use the ideal gas law together with formulas involving molar mass when analysing unknown compounds. These methods are most often used by organic chemists who have made a new molecule and want to identify its chemical structure. To review what you studied regarding molar mass, read through the following example.

What is the molar mass of a pure substance (x) if 0.78 mol of it has a mass of 34.6 g?

This can be solved using factor labelling.

$$M_{(x)} = 34.6\ \text{g} \times \frac{1}{0.78\ \text{mol}}$$
$$= 44\ \text{g/mol}$$

It can also be solved using formulas.

$$M = \frac{m}{n} = \frac{34.6\ \text{g}}{0.78\ \text{mol}} = 44\ \text{g/mol}$$

7. How many grams of CO_2 are in 2.76 mol of CO_2?

Check your answers by turning to the Appendix, Section 2: Activity 6.

Some analytical chemists deal with many types of gas law situations every day.

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8. Turn to page 159 of your textbook and do questions 28 and 29 to see what problems these chemists might tackle.

Check your answers by turning to the Appendix, Section 2: Activity 6.

The ideal gas law is indeed useful for all kinds of gas problems, but in using the ideal gas law, wrong assumptions can often be made. Have you ever assumed something was cool and picked it up and burned your fingers? Or have you ever made other assumptions like your lab partner is recording the data, or you don't need to study because you know the material?

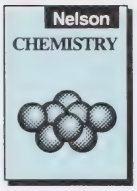
Assumptions can sometimes lead to problems unless, of course, you are aware of the limitations of your assumptions.

ideal gas – a theoretical gas whose particles have no volume and have no attraction or repulsion for each other

You probably assume that $pv = nRT$ always works. It does work frequently – but not always! The $pv = nRT$ formula works for an **ideal gas**. The characteristics of a gas were described in Activity 1.

9. What four characteristics for an ideal gas were listed in Activity 1?

Check your answers by turning to the Appendix, Section 2: Activity 6.



No gas behaves as an ideal gas. The world is full of **real gases**. The ideal gas law works in general for pressures below or equal to 100 kPa – the pressure you would normally see in a lab or other room. Review the top half of page 158 in your textbook to see what real gases are and how they behave.

10. At what temperatures are the volumes and attractions of gas particles likely to deviate from ideal behaviour?

real gas – an actual gas whose particles take up space and have some attractive and repulsive forces between them

11. Indicate which of the following statements illustrate non-ideal behaviour of real gases.

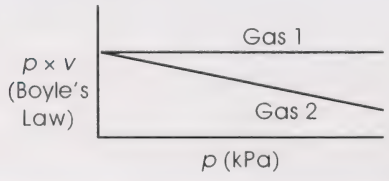
    a. Water vapour condenses at 373 K.

    b. The particles of a gas sample at 500 K and 50 kPa move absolutely randomly.

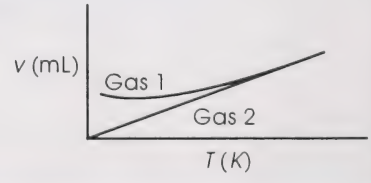
    c. When a sample of H_2 is reduced in temperature to 0 K, the volume is more than 0 mL.

12. For each graph, indicate which gas line represents ideal gas behaviour and which gas line represents real gas behaviour.

a.



b.



Check your answers by turning to the Appendix, Section 2: Activity 6.

Though no gas behaves ideally, in this course assume gases are ideal when you do calculations. Under most conditions your answers will only be out an amount that would be considered a reasonable scientific error. How can you determine the molar mass of a gas experimentally? The following investigation will answer your question.

Investigation 6.1: Determining the Molar Mass of a Gas

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Note: With a little ingenuity, you may be able to do this investigation at home. You could try using a 1 L glass juice jar to collect the gas. The gas volume could be measured by marking the gas level on the jar and then measuring the volume with water and a measuring cup. Otherwise, you will do Part B.

Part A

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Turn to page 160 of your textbook and do Investigation 6.1. While performing the investigation, pay special attention to the required components, safety aspects, and applied science skills.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

Guidelines

- If you do not have access to a barometer, phone the weather office and ask for the atmospheric pressure.
- If you don't have a 600 mL graduated cylinder, use another clear vessel of about the same volume, mark where the gas goes to, and fill it up to the line with water. Then measure the volume of the water with a measuring cup.

13. Show your evidence by completing a table similar to the following.

Mass (g)	T (°C)	T (K)	p (kPa)	v (mL)

As your analysis, do the questions that follow Part B.

Check your answers by turning to the Appendix, Section 2: Activity 6.

End of Part A

Part B

Nelson CHEMISTRY

Read Investigation 6.1: Determining the Molar Mass of a Gas on page 160 of your textbook. Pay special attention to the required components, safety aspects, and applied science skills.

14. To obtain your evidence, copy the information from question 13, Section 2, Activity 6 in the Appendix.

Science Skills

- [ ] A. Initiating
- [ ] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [x] E. Synthesizing
- [x] F. Evaluating

As your analysis, answer the questions that follow Part B.

End of Part B

15. Based on your evidence, calculate the molar mass of butane (C_4H_{10}).

16. Explain the reason for step 4 of the Procedure on page 160 of your textbook with the aid Figure 2.15.

17. a. What is the difference between your calculated molar mass of butane and the actual molar mass value of 58.14 g/mol?

    b. Given the limitations of your equipment, do you think you could justify a molar mass answer to two decimal places (as given in a.)? Explain.

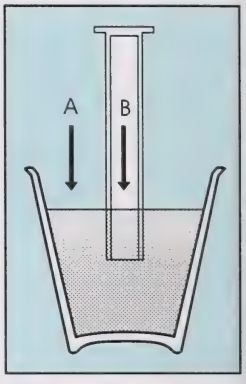
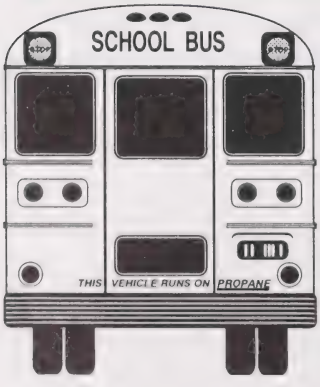


FIGURE 2.15: Step 4

18. How could you improve on the design of this experiment to get a better answer for the molar mass of butane?

Check your answers by turning to the Appendix, Section 2: Activity 6.



The gas laws you have just used to analyse butane are also used to ensure that important industrial gases are handled safely.

Many gases are used as fuels and must be transported from place to place. You or someone you know have probably used two of these types of gases. Methane and propane are commonly used in Alberta.

19. List two uses each for methane and propane.

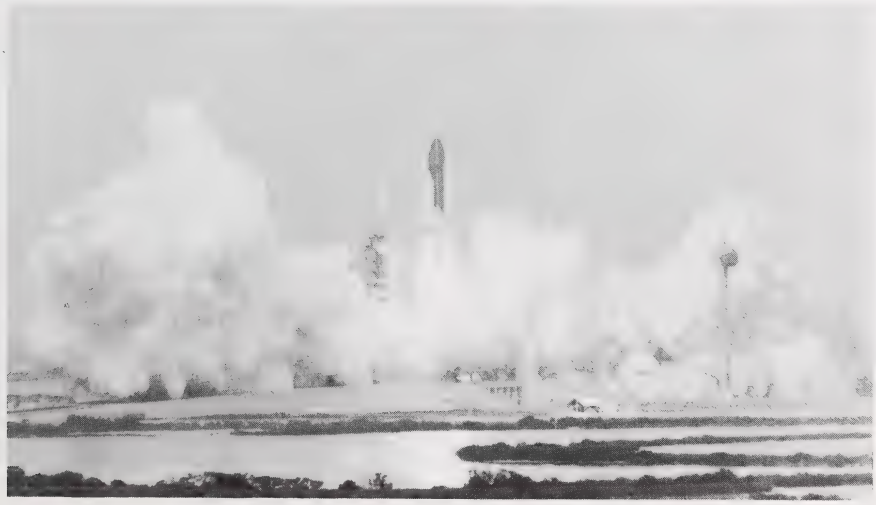
Check your answers by turning to the Appendix, Section 2: Activity 6.

In many houses in rural Alberta, propane is used for heating. In towns and cities, methane is usually used. Since both these fuels are nonrenewable and will run out fairly soon, it has become necessary to look for different fuels or alternative energy sources. Scientists see the next important gaseous fuel as being hydrogen. Study the following information in Figure 2.16 on the uses, availability, energy content, and threat to the environment of methane, propane, and hydrogen.

Name	Hydrogen	Methane	Propane
Formula	H_2	CH_4	C_3H_8
Current Uses	shuttle, prototype cars	cars, barbecues, heating houses	cars, barbecues, heating houses
Energy/Gram	141 kJ/g	55 kJ/g	50 kJ/g
Boiling Point	– 253°C	– 162°C	– 42°C
Natural Availability	none	nonrenewable (will last only a few more dozen years)	
Products of Combustion	H_2O	H_2O, CO_2, CO, hydrocarbons	

FIGURE 2.16: Gases as Fuels

20. By looking at the boiling points of the gases in Figure 2.16, indicate which would be the most difficult to liquify for transport.



NASA

21. Given that the shuttle spacecraft must fly as light as possible, indicate why hydrogen is used as a fuel on the shuttle.

22. What information in Figure 2.16 indicates why methane, $CH_{4(g)}$, and propane, $C_3H_{8(g)}$, are not the fuels of the future?

23. Indicate which of the following explains that $H_{2(g)}$ is the most environmentally friendly of the fuels in Figure 2.16.

    a. It burns hot. b. It's very light. c. It gives off only H_2O.

Check your answers by turning to the Appendix, Section 2: Activity 6.

Have you ever seen hydrogen? It doesn't exist naturally, so if you've ever seen hydrogen, you must have seen someone making it. It is made in classrooms by reacting acids with metals or by using **electrolysis**. Some information on the commercial production of hydrogen, and some of the problems of its use, are contained in Figure 2.17. Study it carefully, and then answer the questions following.

electrolysis – a process of using electricity to cause certain chemical changes to occur

Production of Hydrogen	Problems with Hydrogen
Electrolysis • Water is purified and electrolysed into hydrogen and oxygen gases. $2\,H_2O_{(l)} \xrightarrow{\text{electricity}} 2\,H_{2(g)} + O_{2(g)}$	• Both electrolytic and thermal decomposition production methods are expensive. • Hydrogen is difficult to liquify. • Hydrogen leaks through metal. • Hydrogen is explosive. (e.g., Hindenberg, Challenger) • Liquid hydrogen has a low density. (Eighty litres of gasoline is equivalent to 227 L of hydrogen in energy content.)
Thermal Decomposition • Water is heated to thousands of degrees Celcius until it breaks into its elements. $2\,H_2O_{(l)} \rightarrow 2\,H_{2(g)} + O_{2(g)}$	

FIGURE 2.17: Production and Problems of Working with Hydrogen

24. Why is it a problem that hydrogen is a leaky gas?

25. Match the possible problems with the characteristics of hydrogen.

Problems	Characteristics
a. Accident scenes are more dangerous.	i. leaky
b. Much of the H_2 produced could be lost.	ii. low density
c. The cost of travel will increase.	iii. explosive
d. Half of your car will be a gas tank.	iv. expensive

Frame 1174

If you have access to the laser videodisc set *Cosmic Chemistry*, find and view the sequence that starts with frame 1174, disc side 3. This sequence shows the Hindenberg explosion.

Frame 40632

If you have access to the laser videodisc set *Cosmic Chemistry*, find and view the sequence that starts with frame 40632, disc side 2. This sequence demonstrates a hydrogen-burning vehicle.

The problems of using hydrogen may look insurmountable to you; however, the picture is not as bleak as you may think. New technology is reducing some of the problems. Read through Figure 2.18 to see some of the recent advances.

New Technology – Reduction of Cost

Electrolysis

- New, semi-permeable asbestos membranes are being used so that water purification before electrolysis is cheaper.
- The use of electricity during low usage times to produce $H_{2(g)}$ reduces the costs of production.

Thermal Decomposition

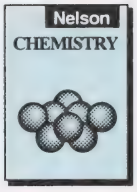
- A new method called thermochemical decomposition only requires a temperature around 800°C.
- New methods using sunlight for energy are being looked at to reduce costs.

FIGURE 2.18: New Technology in Hydrogen Production

26. List three pros and three cons of using hydrogen as a future fuel.

Check your answers by turning to the Appendix, Section 2: Activity 6.

You discovered earlier that you can only predict the behaviour of gases within certain limits of pressure and temperature. You have also seen how important gases are as fuels presently and how they will continue to be important in the future as fuels such as hydrogen take over.



27. To sum up Activity 6, turn to pages 161-163 of your textbook and complete the following questions: 3, 4, 15 (a, b, c), 22, 23, and 24.

Check your answers by turning to the Appendix, Section 2: Activity 6.

Activity 6 has given you a glimpse at the real and ideal worlds of gases. Technology has given society new ways of producing and using gases more efficiently.

Follow-up Activities

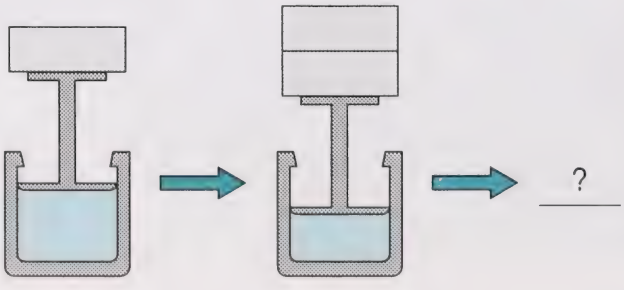
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

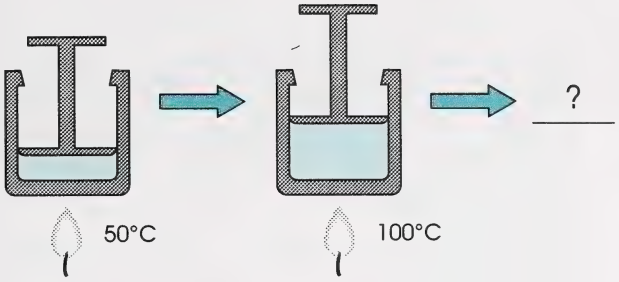
In Section 2 you dealt primarily with an empirical treatment of gases and the theoretical foundation – the kinetic molecular theory.

1. Draw the next picture in each case to illustrate the relationships between p, v, T, and n (the number of moles).

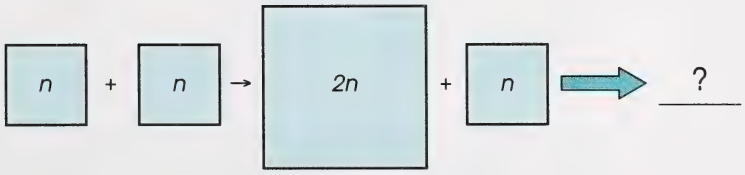
   a. p and v



b. T and v



c. n and v



2. Relate the following empirical characteristics of gases to the situation that best matches them on the right.

Gas Characteristics	Situation
a. compressibility	i. shuffling cards
b. fills the container	ii. a steam roller
c. diffuses	iii. walking too far into a river with rubber boots on

3. Complete the chart.

Law/Theory	Scientist	Variable	Effect on a Volume of Gas if Variable Is Decreased
$p_1v_1 = p_2v_2$		pressure	
$\frac{v_1}{T_1} = \frac{v_2}{T_2}$		temperature	
$\frac{v_1}{n_1} = \frac{v_2}{n_2}$		number of moles	

4. Look at the variables in the following chart and choose the appropriate law or theory that would be used to solve each problem. Choose either Boyle's law, Charles' law, Avogadro's theory, combined gas law, or ideal gas law.

Problem →			Solution
Variable(s) Given (Known)	Variable(s) Changed	Solve for	Law/Theory Used to Solve
p, v	v	p	
v, T	T	v	
p, T, v	p, T	v	
p, T, v, n	p, T, v	n	
v, n	v	n	
p, T, v	p (with v controlled)	T	
p, T, v, n	p, T (with n controlled)	v	

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do any of the following.

1. Explosions usually result from the rapid evolution of gases. Explosives are dangerous but contain very interesting components. Look up the explosives *nitroglycerine* and *TNT* to see what makes these compounds behave as explosives. Concentrate on the reaction they undergo, the products formed, energy released, and their stability.

2. Scuba diving is a fascinating and enjoyable pastime. However, it is potentially very dangerous. Find out what the effects of the high pressure of diving are on the gases in your body. Find out how you can force air into your lungs against such high pressure, how you can be poisoned by oxygen, what the *bends* are, and what causes the *bends*.

3. Do the molecules of all gases have the same velocity at the same temperature? Find out why helium-filled balloons go down so much quicker than balloons filled with nitrogen and oxygen. Graham's law explains this phenomena.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In Section 2 you discovered several properties of gases through the eyes of Boyle, Charles, Gay-Lussac, and Avogadro. The development of the gas laws by these scientists is a good example of the scientific method in action. You also experienced the nature of real and ideal gases and how gases are used in everyday life.

60

Section 2 Assignment: Gases

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Chemistry 20 – Module 2 Section 2 Assignment Page # Name and ID #

Be sure to write legibly. Leave a wide left margin and number all of your pages.

1. You have read about the future use of hydrogen as a fuel. In what two areas should researchers be directing their studies for solving some of the problems of its use? **(2 marks)**

2. Correct this statement: **(2 marks)**

   In a gas at 25°C, the kinetic energy is evenly distributed over a large range.

3. Convert these temperatures. **(2 marks)**

   a. –250°C = _____ K

   b. 450 K = _____ °C

4. a. Draw a graph to illustrate the following experimental results obtained in a gas law investigation. **(3 marks)**

Response Page Setup

Temperature (°C)	0	10	20	30	40
Volume (L)	4.00	4.15	4.29	4.44	4.59

Make sure your graph

- is constructed on graph paper
- has properly labelled horizontal and vertical axes
- has an appropriately-sized scale to include all the data
- has clearly marked data points
- is about 1/3 to 1/2 page in size

b. Which of the gas laws does the data graph illustrate? **(1 mark)**

c. Use the information in the table to mathematically illustrate the appropriate gas law. Show your work. **(3 marks)**

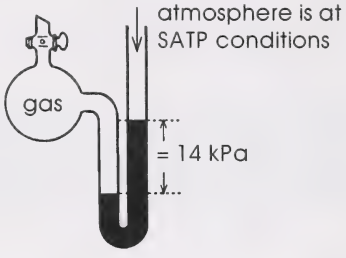
5. a. One mole of ethane gas, $C_2H_{6(g)}$, undergoes a reaction as shown by the following chemical equation. (Pressure and temperature are kept constant.)

$$C_2H_{6(g)} \rightarrow C_2H_{4(g)} + H_{2(g)}$$

If the initial volume of the ethane gas was 150 L, what is the final volume of the products, assuming complete reaction? **(2 marks)**

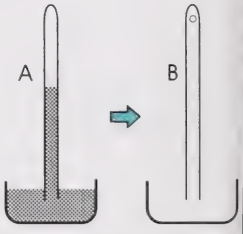
b. Which law or theory does the example in 5. a. illustrate? **(1 mark)**

6. What is the pressure of the gas sample in this manometer? **(1 mark)**



7. Give a molecular interpretation of Boyle's law. **(2 marks)**

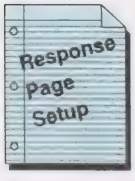
8. a. You are shown the following barometer (A):



Someone drills a hole in the top of the barometer (B).

Draw a diagram to illustrate the resulting fluid levels in this barometer (B).

Reproduce the diagram shown in this question on your response page and then show the appropriate fluid levels as required. **(1 mark)**



b. Explain your drawing. **(2 marks)**

9. How can you increase the average kinetic energy in a glass of water? **(1 mark)**

10. Calculate the new volumes in the following questions. Show your work.

a. A gas with a volume of 2.0 L at 91 kPa expands until its pressure equals 20 kPa. **(3 marks)**

b. Under controlled pressure, 10.0 L of air at – 40°C is warmed to 75°C. **(3 marks)**

11. How many moles of nitrogen gas would occupy 56.0 L at STP? Show your work. **(3 marks)**

12. a. Under what conditions do real gases behave as ideal gases? **(2 marks)**

    b. Why do they behave ideally under these conditions? **(2 marks)**

13. A 7.0 L sample of gas at –20°C has a pressure of 110 kPa. What would its new pressure be if the temperature goes up to 45°C and the volume expands to 11.0 L? Show your work. **(3 marks)**

14. a. From what you have learned about the nature of science and scientific discoveries, what would it take for Avogadro's theory to be discarded? **(1 mark)**

    b. What would happen next? **(1 mark)**

15. What volume will 36.0 g of nitrogen dioxide occupy at SATP? Show your work. **(3 marks)**

16. A volume of 1.0 L of an unknown gas from the atmosphere has a mass of 1.43 g at STP. Do calculations to determine the unknown atmospheric gas. Show your work. **(3 marks)**

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

17. The following information was taken from a lab investigation on the determination of the molar mass of neon gas.

Mass	Volume	Temperature	Pressure
Initial mass of Ne cylinder = 742.20 g Mass after Ne sample is removed = 741.12 g	1414 mL	Room temperature = 22°C	Atmospheric pressure = 97.9 kPa

    a. From the data given, what is the calculated molar mass of neon? Show your work. **(3 marks)**

    b. From your preceding calculation, which two of the following would account for experimental error? **(2 marks)**

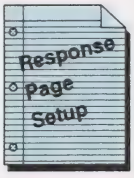
        i. The thermometer reads too low.

        ii. The thermometer reads too high.

        iii. The graduated cylinder reads too high.

        iv. The graduated cylinder reads too low.

c. Just after your experiment, it was found that the atmospheric pressure had fluctuated wildly during the experiment. Considering your answer to 17. a., do a calculation to show that there is a good chance the atmospheric pressure was lower than you thought during the experiment. Show your work. **(3 marks)**



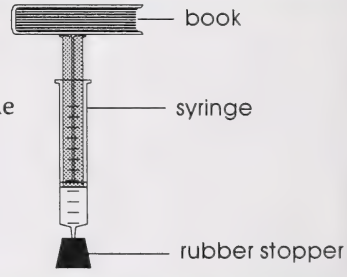
Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

Self:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐
Teacher:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

18. A student performed an experiment to confirm Boyle's law. The experimental apparatus was the same as in the investigation on Boyle's law in Section 2: Activity 2. The student followed the same procedure as in Activity 2, placing identical books on the syringe, one at a time, and taking volume readings for each book.



The following data were collected:

Number of Books (pressure)	Syringe Volume (mL)
0	40.0
1	35.0
2	30.2
3	26.2
4	23.0
5	20.5

The student then analysed the data to confirm Boyle's law. The student used the number of books as the relative pressure added. Then the student multiplied the number of books (pressure) by the syringe volume. The following table contains the results.

Number of Books (pressure)	Syringe Volume (mL)	$p \times v$
0	40.0	0.0
1	35.0	35.0
2	30.2	60.4
3	26.2	78.6
4	23.0	92.0
5	20.5	102.5

a. Within normal experimental error (less than 5%) did the student confirm Boyle's law? Explain. **(2 marks)**

b. Evaluate the analysis the student performed and discuss possible reasons for error. (1/4 to 1/3 page) **(3 marks)**

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

Self:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐
Teacher:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐

MODULE SUMMARY

In Module 2 you learned to characterize aqueous systems in terms of $\left[H^{+}_{(aq)}\right]$ and pH. You found that knowledge of these characteristics enables you to predict empirical characteristics of solutions. The importance to the home and industry of solutions that span the entire pH scale was illustrated.

Also in Module 2 you examined a model of the gaseous states. This simplest of three states gave you clues as to how molecules behave and how you can influence their behaviour. You learned how the behaviour of real particles can be predicted with reasonable accuracy using a model built upon theoretical, ideal particles.

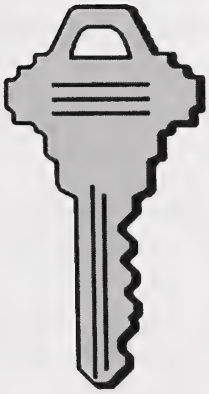
To ensure that all of your work has been completed in a satisfactory manner, check off the items in the following list:

- ❑ Section 1 Assignment has been completed.
- ❑ Section 2 Assignment has been completed.
- ❑ Your responses are organized and neat, with room for teacher comments.
- ❑ All your response pages are numbered consecutively and identified with this heading.

Chemistry 20 – Module 2 Section # Assignment Page # Name and ID #

Submit **only** your **assignment response pages** for evaluation.

Appendix



Glossary

Activities

Extra Help

Enrichment

Glossary

acid: a molecular substance which, when put into water, will increase the concentration of hydrogen ions

barometer: an instrument used to measure atmospheric pressure

base: an ionic substance which, when put into water, will increase the concentration of hydroxide ions

caustic: a substance that burns or destroys organic tissue

controlled variable: a variable that must be kept constant because it will affect the responding variable

corrosive: the ability to cause oxidation (loss of electrons)

diffuse: to move and spread freely

dissociation: a process whereby an ionic compound separates into its ions

effusion: movement of substances (usually gases) through a small opening

electrolysis: the process of using electricity to cause certain chemical changes to occur

empirical definition: a definition based on observable properties

ideal gas: a theoretical gas whose particles have no volume and have no attraction or repulsion for each other

ideal gas law: $pv = nRT$

indicator: a weak acid that changes colour when it ionizes

ionization: a process whereby molecular compounds form ions

Kelvin: a temperature scale in which water freezes at 273°C and boils at 373°C

kilopascal: a unit of pressure equal to 1000 N/m^2

kinetic energy: energy associated with motion

logarithm: a number representing a power of another number; base 10 logarithms are powers of 10

manipulated variable: the variable that is purposely changed by the scientist

manometer: an instrument used to measure the pressure of a confined gas

neutralization: a reaction that eliminates the active properties of an acid or base

neutral solution: a solution that shows neither acidic nor basic properties

pH: a logarithmic scale that indicates how acidic or basic a solution is; $pH = -\left(\log\left[H^{+}_{(aq)}\right]\right)$

real gas: an actual gas whose particles take up space and exhibit some attractive and repulsive forces between them

responding variable: the variable that changes as a result of the changing of the manipulated variable

species: a term denoting an atom, ion, or compound

strong acid: a type of acid that will fully ionize when dissolved in water

theoretical definition: a definition that explains why something behaves the way it does

weak acid: a type of acid that will not fully ionize when put into water

Suggested Answers

Section 1: Activity 1

1.

Acids	Bases
turn litmus red	turn litmus blue
are electrolytes	are electrolytes
neutralize bases	are slippery
taste sour	neutralize acids
react with metals to produce hydrogen gas	taste bitter

2. a. To classify the solutions as either acidic, basic, or neutral, each one should be tested with both red and blue litmus paper.

   b. In an acidic solution, blue litmus would turn red. In a basic solution, red litmus would turn blue. A neutral solution would have no effect on red or blue litmus.

3. Textbook question 5:

   a. $H_3PO_{4(aq)}$

   b. $H_2SO_{3(aq)}$

   c. $HNO_{3(aq)}$

   d. $CH_3COOH_{(aq)}$

   e. $HI_{(aq)}$

   Textbook question 6:

   a. aqueous hydrogen sulphate – sulphuric acid

   b. aqueous hydrogen carbonate – carbonic acid

   c. aqueous hydrogen sulphide – hydrosulphuric acid

   d. aqueous hydrogen hydrochlorite – hypochlorous acid

   e. aqueous hydrogen benzoate – benzoic acid

4. Sodium hydroxide, calcium hydroxide, and aluminum hydroxide all have the hydroxide ion in common, and all are ionic compounds.

5. Arrhenius said an acid is any substance which when dissolved in water increases the hydrogen ion concentration.

6. Arrhenius said a base is any substance which when dissolved in water increases the hydroxide ion concentration.

7. a. HI undergoes ionization in solution.

   b. $Ca(OH)_2$ undergoes dissociation in solution.

8.

Characteristic	Acidic, Basic, or Neutral Substance	Empirical or Theoretical Definition
turns litmus blue	basic	empirical
contains many OH^-	basic	theoretical
neutralizes acids	basic	empirical and theoretical
tastes sour	acidic	empirical
no affect on litmus	neutral	empirical

9. A soluble molecular substance would give you a neutral non-electrolytic solution. A neutral ionic substance would give you a neutral electrolytic solution (no OH^- ions).

10. $HCl_{(aq)} + KOH_{(aq)} \rightarrow \underset{\text{neutral ionic}}{\mathbf{KCl_{(aq)}}} + \underset{\text{water}}{\mathbf{H_2O_{(l)}}}$

11. a. $HNO_{3(aq)} + CsOH_{(aq)} \rightarrow \mathbf{CsNO_{3(aq)}} + \mathbf{H_2O_{(l)}}$

b. $H_2SO_{4(aq)} + 2\,NH_4OH_{(aq)} \rightarrow \mathbf{(NH_4)_2SO_{4(aq)}} + \mathbf{2\,H_2O_{(l)}}$

c. $Ca(OH)_{2(aq)} + 2\,HBr_{(aq)} \rightarrow \mathbf{CaBr_{2(aq)}} + \mathbf{2\,H_2O_{(l)}}$

12. $OH^-_{(aq)}$ from the calcium hydroxide and aluminum hydroxide react with $H^+_{(aq)}$ from the stomach acid to give water.

$$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$$

13. The other ions are unchanged by the neutralization. They are aqueous on both product and reactant sides and do not participate; they are called spectator ions!

14. Four solutes are dissolved to make solutions and then tested with both a conductivity apparatus and litmus paper.

15. The following materials are used in this investigation:

- glucose
- calcium chloride
- citric acid
- calcium hydroxide
- conductivity apparatus
- litmus paper
- four test tubes (or small beakers)
- distilled water

16. The procedure for this investigation is as follows:

- Add 1 mL (1/4 tsp.) of each solute to a labelled test tube (or beaker).
- Add 10 mL of distilled water and gently shake to dissolve solutes.
- Test each solution for conductivity with the conductivity tester. Record your results.
- Test each solution with litmus. Record your results.
- Carefully discard the solutions down the sink.

17.

Solution	Litmus	Conductivity
1	red litmus → blue	high
2	no change	none
3	no change	high
4	blue litmus → red	high

18. a. Solute 1 is $Ca(OH)_2$ because it tests as a base. $Ca(OH)_2$ is an ionic hydroxide and therefore a base.

b. Solute 2 is glucose because it is a molecular compound. It has no acidic characteristics and tests as a non-electrolyte.

c. Solute 3 is calcium chloride because it is an electrolyte but not a base. Calcium chloride is a soluble ionic substance which dissociates in water.

d. Solute 4 is citric acid because it is an electrolyte and turns litmus red.

19. Textbook question 6:

Experimentally, acids and molecular compounds differ in that acids cause blue litmus to turn red and molecular compounds have no effect on litmus. Theoretically, acids ionize in water to form $H^+_{(aq)}$ ions and molecular compounds do not. Many acids are molecular when pure and are sometimes referred to in pure form as acid-forming compounds.

Textbook question 15:

a. To distinguish between a solution of an ionic compound and a solution of a molecular compound, test each solution for conductivity. The solution that contains an electrolyte (lights up) is the ionic solution.

b. To distinguish between a solution of an acid and a solution of a base, test each solution with litmus paper. The solution that turns litmus blue is a base. The solution that turns litmus red is an acid.

c. To distinguish between a solution of a molecular compound and pure water, heat a drop of both on a slide (or in a beaker) over a bunsen burner. The one that leaves no mark on the slide is the pure water sample.

Textbook question 20:

The solution is basic, so it is ionic and its negative ion must be $OH^-_{(aq)}$. You must choose a positive ion that is not soluble with sulphate ions (since $OH^-_{(aq)}$ is soluble with sodium). Some choices are Ba^{2+}, Sr^{2+}, or Ca^{2+}. Therefore, one possible chemical formula could be $Ba(OH)_2$.

Section 1: Activity 2

1. A series of solutions will be tested with litmus to see if they are acidic, basic, or neutral.

2. The list of materials may include the following:

- vinegar
- antacid tablets
- baking powder
- window cleaner
- pop
- milk
- shampoo
- lime
- coffee
- drain cleaner
- tap water
- lemon
- ketchup
- pickles
- boric acid (borax)
- trisodium phosphate
- dish detergent
- ASA
- vitamin C
- oven cleaner
- distilled water
- test tubes
- litmus paper (blue and red)

3. The investigation procedure is as follows:

- Gather together as many of the substances as you can obtain.
- Make solutions of baking powder, drain cleaner, boric acid, trisodium phosphate, ASA, vitamin C, or other solids by taking 1 mL (1/4 tsp. or a pea-sized amount) of each and dissolving it in a test tube with 10 mL of distilled water.
- Test each solution with both blue and red litmus paper.
- Record the observations in an evidence table.

4.

Substance	Effect on Litmus	Acid/Base/Neutral	Cleaner	Edible
vinegar	B → R	acid	✔	✔
antacid tablets	R → B	base		✔
baking powder	R → B	base		✔
window cleaner	R → B	base	✔	
pop	B → R	acid		✔
milk	none	neutral		✔
shampoo	none	neutral	✔	
coffee	B → R	acid		✔
drain cleaner	R → B	base	✔	
tap water	none	neutral	✔	✔
lemon	B → R	acid		✔
ketchup	B → R	acid		✔
garden lime	R → B	base		
pickles	B → R	acid		✔
boric acid	B → R	acid		
trisodium phosphate	R → B	base	✔	
dish detergent	R → B	base	✔	
ASA	B → R	acid		✔
vitamin C	B → R	acid		✔

Substance	Effect on Litmus	Acid/Base/Neutral	Cleaner	Edible
cream of tartar	B → R	acid		✔
over cleaner	R → B	base	✔	
bleach	R → B	base	✔	

5.

Acids	Bases	Neutral Substances
• vinegar • pop • coffee • lemon • ketchup • pickles • boric acid • ASA • vitamin C • cream of tartar	• antacid tablets • baking powder • window cleaner • drain cleaner • garden lime • trisodium phosphate • dish detergent • oven cleaner • bleach	• milk • shampoo • tap water

6. In general, commercial cleaners are bases. Ammonia, drain cleaner, trisodium phosphate, dish detergent, and oven cleaner are examples. Shampoos are treated to give a nonbasic product, which appeals to the public. Most acids are not used as cleaners, although vinegar and boric acid are exceptions.

   In general, acids in the home are edible. Vinegar, tonic water, coffee, lemon, pickles, Aspirin, vitamin C, and cream of tartar are acids. Apparently the sour taste of acids is preferred to the bitter taste of bases. Exceptions are milk of magnesia, which is taken internally only to neutralize excess stomach acids, and baking soda, which is included in recipes only to mix with acids (perhaps cream of tartar) in a neutralization reaction to produce $CO_{2(g)}$ (e.g., to fluff up muffins).

7. Common industrial acids include sulphuric, hydrochloric, phosphoric, oxalic, and nitric acids. Common industrial bases include lime, sodium hydroxide, and ammonia (ammonium hydroxide).

8. NaOH and H_2SO_4 are seen as industrially important because both compounds have common names and because both are involved in a large number of industries.

9. Both compounds, NaOH and H_2SO_4, are involved in types of soaps, dyes, pharmaceuticals, metallurgy, and petroleum industries.

10. a. When you make sodium hydroxide, you also make the poisonous gas chlorine.

    b. Chlorine, Cl_2, is often used to control bacterial growth in swimming pools. It's the material that hurts your eyes. It is more commonly added as $NaOCl_{(aq)}$. Chlorine is also used in bleach.

11. Alberta is a good place to have an H_2SO_4-producing plant because the province has sulphur for the raw material used in H_2SO_4 production.

12. Strong acids ionize more completely than weak acids causing a larger increase in $H^+_{(aq)}$ ions in solution.

13. Boric acid is a weak acid.

14.

Acid	Strength
$HClO_2$	weak
$HClO_4$	strong
C_6H_5COOH	weak
H_3PO_4	weak

15. a. In $HCl_{(aq)}$ the following major entities are present in the water environment: $H^+_{(aq)}$, $Cl^-_{(aq)}$, $H_2O_{(l)}$.

b. In $HNO_{2(aq)}$ the following major entities are present in the water environment: $HNO_{2(aq)}$, $H_2O_{(l)}$.

c. In $CH_3COOH_{(aq)}$ the following major entities are present in the water environment: $CH_3COOH_{(aq)}$, $H_2O_{(l)}$.

16. If a solution doesn't have very many moles of solute per litre, it is a dilute solution.

17. a. Nitric acid ionizes. $HNO_{3(aq)} \rightarrow H^+_{(aq)} + NO_3^-(aq)$

b. Strontium hydroxide dissociates. $Sr(OH)_{2(s)} \rightarrow Sr^{2+}(aq) + 2\ OH^-(aq)$

18. a. Two moles of $OH^-_{(aq)}$ ions form from one mole of $Ca(OH)_2$. Therefore, $\left[OH^-_{(aq)}\right] = 2 \times 0.60\ mol/L$
$= 1.20\ mol/L$

b. Three moles of $OH^-_{(aq)}$ form from one mole of $Al(OH)_3$. Therefore, $\left[OH^-_{(aq)}\right] = 3 \times 0.52\ mol/L$
$= 1.56\ mol/L$

c. One mole of $OH^-_{(aq)}$ forms from one mole of $NaOH$. Therefore, $\left[OH^-_{(aq)}\right] = 1 \times 0.86\ mol/L$
$= 0.86\ mol/L$

d. The aluminum hydroxide is the most basic because its $\left[OH^-_{(aq)}\right]$ is the largest.

19. a. ii $HCl_{(aq)}$ is strong and will dissociate completely.

b. iii $CH_3COOH_{(aq)}$ is weak and won't dissociate completely.

c. i $H_2SO_{4(aq)}$ is a strong acid with two $H^+_{(aq)}$ ions/molecule.

20. Because they don't ionize one hundred percent, and you don't know what percent they do ionize, you cannot calculate the $H^+_{(aq)}$ concentration of a weak acid solution.

21.

Safe Practices	Emergency Procedures
• Wear goggles and an apron. • Keep chemicals away from the lab book or the edge of the table. • Know the location of the nearest safety equipment. • Do only what the lab procedure says. • When acids are diluted, always add the acid to the water to prevent a large heat build-up. • Use only small amounts of acid. • Do not wear contact lenses in the lab.	• If you spill an acid or a base, notify those around you. • Use gloves when cleaning up a large spill. • Clean up spills immediately. • Use acid or base neutralizer on an acid or base spill. • When you get acid on you, flush the area with water. • Treat an acid spill on your skin immediately.

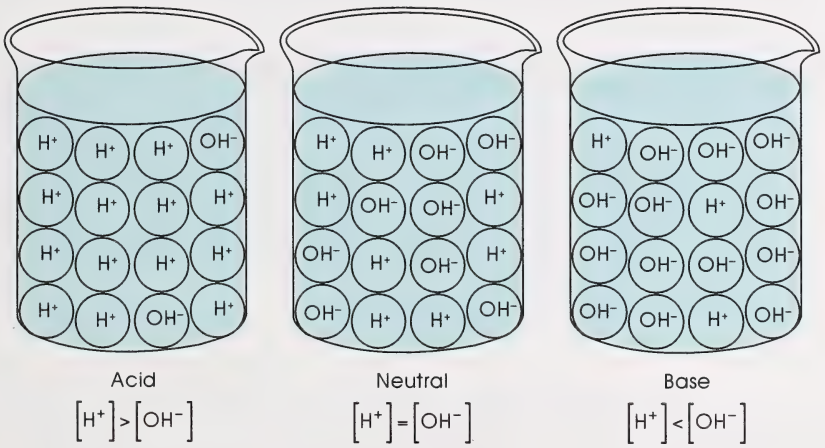
Section 1: Activity 3

1. a. $\left[H^+_{(aq)}\right] > 10^{-7}$ mol / L b. $\left[H^+_{(aq)}\right] = 10^{-7}$ mol / L c. $\left[H^+_{(aq)}\right] < 10^{-7}$ mol / L

2. a. $pH = -\left(\log\left[H^+_{(aq)}\right]\right)$ b. The measure of acidity or basicity of a solution is pH.

3. The self-ionization of water is the source of $H^+_{(aq)}$ ions in a neutral solution. $H_2O_{(l)} \rightarrow H^+_{(aq)} + OH^-_{(aq)}$

4.



5. a. The pH values of acids are less than seven (pH < 7).

   b. The pH values of bases are greater than seven (pH > 7).

6. a. Solutions A and B are two pH units apart.

   b. The two solutions must be 10 × 10 = 100 concentration factors apart or 10^2.

7.

$[H^+]$ (mol/L)	pH	Acidic/Basic/Neutral
10^{-4}	4	**acidic**
10^{-7}	**7**	neutral
10^{-10}	10	basic
10^{-2}	**2**	**acidic**
10^{-9}	9	**basic**
10^{-12}	**12**	**basic**
10^{-3}	3	**acidic**
10^{-8}	**8**	**basic**

8. The solution of 10^{-8} mol / L has a larger $[H^+_{(aq)}]$ because 10^{-8} mol / L is a larger number than 10^{-10} mol / L. Its solution is 100 times more concentrated.

9. The pH of the 10^{-10} mol / L solution is larger at 10 than the pH of the 10^{-8} mol / L solution where pH = 8.

10. a. The larger the pH value is, the smaller the $[H^+_{(aq)}]$ and the more basic the solution.

    b. The smaller the pH value is, the greater the $[H^+_{(aq)}]$ and the more acidic the solution.

11. Textbook question 23:

    a. 10^{-7} mol / L b. 10^{-11} mol / L c. 10^{-2} mol / L d. 10^{-4} mol / L e. 10^{-14} mol / L

    Textbook question 24:

    a. pH = 3 b. pH = 5 c. pH = 7 d. pH = 10

    Textbook question 25:

    To neutralize the sample, the hydrogen ion concentration would have to be decreased by a factor of 100. Moving one pH unit represents a factor of 10. So, moving two pH units, pH = 5 to pH = 7, represents 10 × 10 or a factor of 100.

    Textbook question 26:

    a. There are 1×10^{-1} mol of $H^+_{(aq)}$ in 100 L of wine.

$$n = Cv$$
$$= 1 \times 10^{-3}\ \text{mol/L} \times 100\ \text{L}$$
$$= 1 \times 10^{-1}\ \text{mol}\ H^+_{(aq)}$$

or

$$n = 100\ \cancel{\text{L}} \times \frac{1 \times 10^{-3}\ \text{mol}\ H^+_{(aq)}}{\cancel{\text{L}}}$$
$$= 1 \times 10^{-1}\ \text{mol}\ H^+_{(aq)}$$

b. There are 1×10^{-6} mol of $H^+_{(aq)}$ in 100 L of sea water. $n = 100 \cancel{L} \times \frac{1 \times 10^{-8} \text{ mol}}{\cancel{L}}$

$= 1 \times 10^{-6} \text{ mol } H^+_{(aq)}$

c. There are 5 mol of $H^+_{(aq)}$ in 100 L of stomach acid. $n = 100 \cancel{L} \times \frac{0.05 \text{ mol}}{\cancel{L}}$

$= 5 \text{ mol } H^+_{(aq)}$

12. Five solutions will be identified by testing for conductivity and pH.

13. The following procedure may be used:

- Dissolve 1 mL of sugar (1/4 tsp. or a pea-sized amount) in 10 mL of water in a test tube. Label this test tube 5. This test tube is essentially a control.
- Label four other test tubes with numbers from one to four and add the unknown solutions to the appropriate test tube.
- Test each solution for conductivity with the conductivity apparatus and record your results.
- Test each solution with universal pH paper, compare to the colour standards, and record your results.

14.

Solution	Conductivity	pH
1	✔	13
2	✔	1
3	✔	7
4	poorly	3
5	✔	7

15. a. Solution 1 is KOH because it tested as the only base (pH = 13).

b. Solution 2 is $HCl_{(aq)}$ because it tested as a strong acid (pH = 1).

c. Solution 3 is $KBr_{(aq)}$ because it tested as an electrolyte but not an acid or base.

d. Solution 4 is acetic acid because it tested as an electrolyte and a weaker acid than $HCl_{(aq)}$.

e. Solution 5 is confirmed as sucrose because it tested as a neutral non-electrolyte.

16. Litmus could distinguish between a pH of 3 (red) and a pH of 9 (blue). One value must be acidic and the other basic.

17. Litmus could not distinguish a pH of 3 (red) and a pH of 6 (red). In other words, litmus could not distinguish between two acid pH values or two base pH values.

18. If methyl orange is red, the pH of a solution must be **between 1 and 3 or pH < 3.**

19. Indigo carmine would be green if placed in an $NaOH_{(aq)}$ solution of pH = 12.

20. The pH must be 4.6-4.7 because

    - HMo – Yellow indicates pH > 4.6.
    - HMr – Red indicates pH < 4.7.

21. From the information, the pH of the solution must be between about 6 and 8.

    - HMo – Yellow indicates pH > 4.6.
    - HMr – Yellow indicates pH > 6.0.
    - HPh – Colourless indicates pH < 8.2.
    - HIc – Blue indicates pH < 11.4.

22. Following are ways lime is used in the environment and in industry:

    - Lime precipitates impurities from sewage.
    - Lime reduces acidity in rivers in coal-mining country.
    - Lime is used in coal-burning power plants to reduce acidity by 90%.

23. The $H^+_{(aq)}$ ion is common to all acid/base reactions.

24. a. A pH meter measures the relative acidity or basicity of a solution by measuring pH.

    b. The pH meter works by measuring the concentration of $H_3O^+_{(aq)}\left(H^+_{(aq)}\right)$ ions in solution and converting it to pH.

25. A strong acid ionizes completely in solution to produce many $H_3O^+_{(aq)}$ ions; a weak acid produces relatively few hydronium ions.

26. a. Acid rain is mainly caused naturally by forest fires (through $CO_{2(g)}$) and volcanic eruptions $\left(SO_{2(g)}\right)$.

    It is also caused by emissions of nitrogen and sulphur oxides $\left(NO_x + SO_x\right)$ from factories and refineries.

    b. Acid rain causes damage to plant and animal life in the environment and causes erosion of statues and buildings made of limestone and marble.

    c. Society is working towards reducing emissions that cause acid rain. People are also reducing acidity by using knowledge of proton $\left(H^+\right)$ transfer.

27.

Item	Dangerous	Needs Safeguards	Has Benefits	Generally Good	Generally Bad
Orange juice			✔	✔	
Concentrated H_2SO_4	✔	✔	✔		✔
Distilled water			✔	✔	
Vinegar			✔	✔	
Lime	✔	✔	✔		✔

H_2SO_4 and lime are potentially dangerous because even though they have many uses, which is good, they can also cause injury, which is bad.

28. a. Either A or B could be chosen depending on your opinion. One opinion is that the benefits and safeguards outweigh the dangers because of the incredible number of jobs that depend on these chemicals and the relatively few accidents that occur with them. On the other hand, your opinion may be that as long as there is any risk at all, it is not worth it.

b. Some reasons for choosing A are the following:

- The potential dangers to health seem to be growing.
- The planet can only stand so many more environmental accidents.

Some reasons for choosing B are the following:

- Many goods are made using them.
- Many jobs depend on them.
- Relatively few accidents occur.

29. To decide whether the safeguards are good enough you would need detailed information on how many injuries occurred while having the present safeguards in place. You may also want to look back and see how many accidents happened when the safeguards were different.

30. The following WHMIS labels would be found at a production site for H_2SO_4:

Class C: Oxidizing material

Class D: Poisonous and infectious material 1. Materials causing immediate and serious toxic effect

Class E: Corrosive material

Class F: Dangerously reactive material

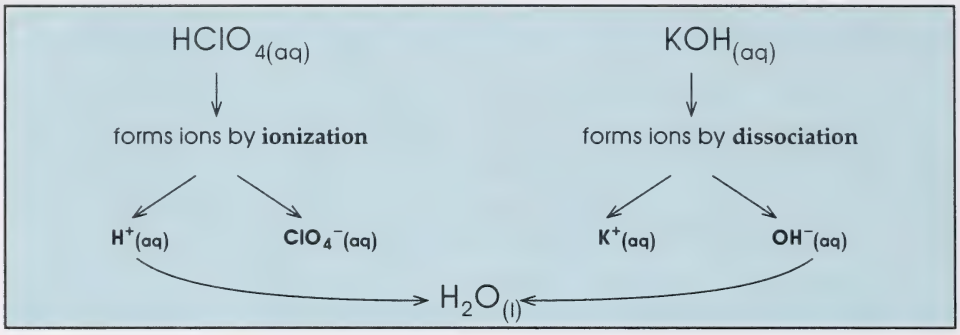
Section 1: Follow-up Activities

Extra Help

1.

Acids	Bases
• turn litmus red • **are electrolytes** • **neutralize bases** • **taste sour** • **react with metals to produce hydrogen**	• turn litmus blue • **are electrolytes** • **neutralize acids** • **taste bitter** • **feel slippery**

2.



3. a. T

b. F – Litmus only tells you if the solution has a pH of > 7 or < 7.

c. T

d. F – If neutralization occurs, pH should be closer to 7.

e. T

4. a. B d. A and B g. A and B j. B

b. A e. A and B h. A and B k. A

c. A f. A and B i. A and B l. B

5.

$[H^+(aq)]$ (mol/L)	pH	Acid/Base/Neutral
10^{-1}	**1**	**acid**
10^{-2}	**2**	**acid**
10^{-3}	3	**acid**
10^{-4}	**4**	**acid**
10^{-5}	5	**acid**

$[H^+_{(aq)}]$ (mol/L)	pH	Acid/Base/Neutral
10^{-6}	6	**acid**
10^{-7}	**7**	**neutral**
10^{-8}	8	**base**
10^{-9}	**9**	**base**
10^{-10}	**10**	**base**
10^{-11}	11	**base**
10^{-12}	12	**base**
10^{-13}	**13**	**base**
10^{-14}	14	**base**

6. Any three of the several aspects discussed in Section 1, Activity 3 can be answers in the three categories. The following are examples.

Dangers	Safeguards	Benefits
costly evaluation	shortest possible route chosen	provides many consumer goods
soil and ground water pollution	no transport at rush hour	uses up sulphur from gas plants
human injury from contact	specialized transport equipment for specific chemicals	provides jobs in the chemical industry

Enrichment

1. Answers are provided for both the scientific perspective and the technological perspective.

Scientific Perspective

Acid rain is due to the reaction of nonmetallic oxides like CO_2, NO_2, SO_3, and SO_2 reacting with water in the atmosphere to form acids in the following ways:

$CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$ (carbonic acid); $3\,NO_{2(g)} + H_2O_{(l)} \rightarrow 2\,HNO_{3(aq)}$ (nitric acid) $+ NO_{(g)}$

$SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$ (sulphurous acid); $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$ (sulphuric acid)

The chemical damage statues undergo results from acids reacting with the ionic carbonates from which limestone and marble statues are made:

$CaCO_{3(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(s)} + H_2CO_{3(aq)}$

The softer $CaSO_4$ is easily eroded from the surface of the statue.

Acid rain also reacts with metals causing Zn and Cu pipes to corrode. As a matter of fact, white-haired people have seen their hair turn green because of the copper in their water pipes. These people drank the water containing copper ions from corroded Cu pipes.

Technological Perspective

One technological response to acid rain is to use fuels with less sulphur in them. Some types of coal contain less sulphur than others. Also, $SO_{2(g)}$ is captured in reactions such as

$$SO_{2(g)} + Ca(OH)_{2(s)} \rightarrow CaSO_{3(s)} + H_2O_{(l)}$$

Another oxide produced that causes acid rain is $NO_{2(g)}$. Eighty percent of new cars have catalytic converters, inside of which are the elements rhodium, platinum, and some transition metal oxides. These chemicals catalyse the conversion of the oxides of nitrogen to nitrogen and oxygen:

$$2\,NO_{2(g)} \xrightarrow{\text{catalyst}} N_{2(g)} + 2\,O_{2(g)}$$

2. Melted sulphur is burned forming $SO_{2(g)}$. The $SO_{2(g)}$ is cleaned with water and then dried with concentrated $H_2SO_{4(aq)}$. (H_2SO_4 absorbs water.) In the presence of a V_2O_5 catalyst, $SO_{2(g)}$ reacts with $O_{2(g)}$ to give $SO_{3(g)}$. This reaction takes place where the two gases contact a catalyst, so the process is called the contact process. The $SO_{3(g)}$ is then passed through concentrated $H_2SO_{4(aq)}$ giving $H_2S_2O_{7(g)}$ (fuming sulphuric acid). When water is added to this, it changes to $H_2SO_{4(aq)}$:

$$H_2S_2O_{7(g)} + H_2O_{(l)} \rightarrow 2\,H_2SO_{4(aq)}$$

$H_2SO_{4(aq)}$ is such a strong dehydration compound that not only can it take water from gases, like $SO_{2(g)}$, but it can also take water from molecules like $C_{12}H_{22}O_{11(s)}$ (sucrose – table sugar).

$$C_{12}H_{22}O_{11(s)} + 11\,H_2SO_{4(aq)} \rightarrow 12\,C_{(s)} + 11\,H_2SO_4 \cdot H_2O_{(aq)}$$

3. Hydrofluoric acid reacts with glass (SiO_2) in the following reaction:

$$SiO_{2(s)} + 4\,HF_{(aq)} \rightarrow SiF_{4(g)} + 2\,H_2O_{(l)}$$

Therefore, $HF_{(aq)}$ must be stored in Teflon® containers.

This reaction supports the glass-etching industry. If a glass surface is to be etched with $HF_{(aq)}$, the parts you don't want to react are covered with wax. Then the $HF_{(aq)}$ reacts with only the exposed glass. You have probably seen decorative glass etching in glass doors and windows. It is also used to etch lines on lab equipment like volumetric flasks and to etch the insides of light bulbs for softer light.

Section 2: Activity 1

1. There are many possible choices. Here are four examples.

   - Neon is used in many forms of fluorescent lights.
   - Helium is used to raise weather balloons high into the atmosphere.
   - Methane (natural gas), $CH_{4(g)}$, is used as a fuel for heating.
   - Hydrogen is used as a fuel to propel space vehicles (such as the space shuttle).

2. Statements a, b, and d support the kinetic molecular theory.

3. The atoms or molecules are most isolated or independent in container $c_{(g)}$, the container containing a gas.

4. a. This example illustrates the enormous amount of space between the CO_2 molecules in the gaseous phase.

   b. Gases take up a large volume since the molecules spread out greatly.

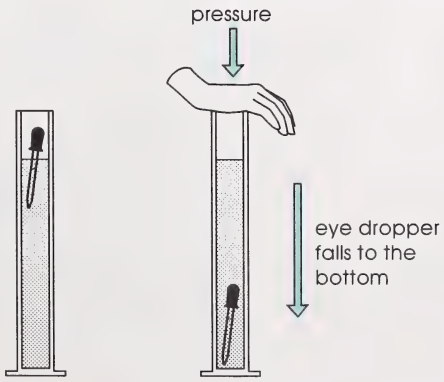
5.

Empirical Property	Theoretical Characteristic of Gases
Gases completely fill containers.	• Gas particles do not attract or repel each other. • Gas particles move in straight lines except when they collide with each other or the container.
Gases are compressible.	• Molecules and atoms of gases are particles of negligible volume compared to the spaces between them. • Gas particles do not attract or repel each other.
Gases can diffuse through each other.	• Gas particles do not attract or repel each other. • Gas particles move in straight lines except when they collide with each other or the sides of the container.

6. a. A c. A e. B g. B

   b. C d. C f. A

7. The gas in the eyedropper was observed to decrease in volume. See the following diagram .

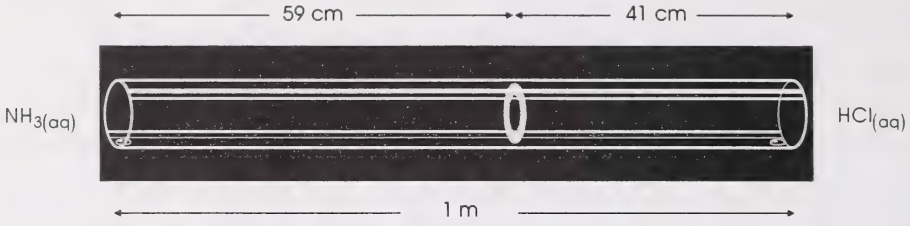


8. Very little pressure was required to make the gas compress because there is a lot of space between the gas particles.

9. No, neither the liquid in the container or the container itself was observed to compress or swell.

10. The gas compressed because there are large spaces between particles in gas. Particles in liquids and solids are fairly close together, so neither of them compressed.

11. a. A white precipitate formed around the inside of the tube as shown after approximately fifteen minutes.



b. Distance from start of $HCl_{(g)}$ to precipitate = 59 cm

Distance from start of $NH_{3(g)}$ to precipitate = 41 cm

12. See the answer for the preceding question (question 11, Section 2, Activity 1).

13. $NH_{3(g)}$ diffused the fastest because $NH_{3(g)}$ went 59 cm in the same time that $HCl_{(g)}$ went 41 cm. This is apparent because the precipitate formed where the gases met.

14. The molecules encounter $N_{2(g)}$ and $O_{2(g)}$ molecules from the air in the tube and take a random pathway from the ends of the tube toward the middle. Many collisions take place, so it's not a straight-line trip for the NH_3 and HCl molecules. This means it takes a while for the molecules to diffuse toward the middle of the tube.

15. a. The white precipitate that formed was a product of the reaction between $NH_{3(g)}$ and $HCl_{(g)}$.

$$NH_{3(g)} + HCl_{(g)} \rightarrow NH_4Cl_{(s)} \text{ (ammonium chloride)}$$

b. The product was a solid because, as an ionic compound, ammonium chloride is a solid in its natural state.

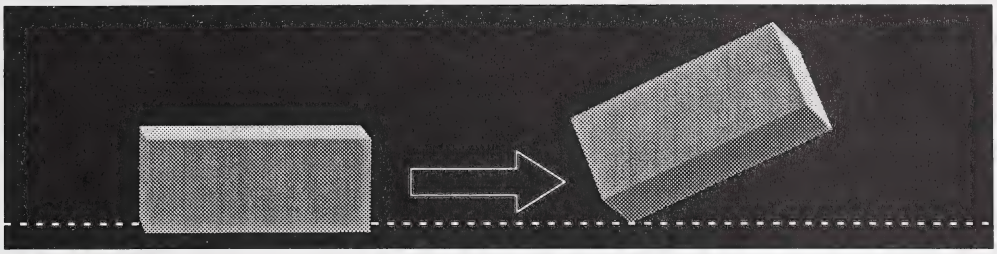
Section 2: Activity 2

1. It is the force exerted by the collision of the gas particle against the side of the container that causes pressure to be exerted.

2. a. This is a low-pressure situation because weight is distributed over a large area.

   b. This is a high-pressure situation because weight is concentrated in a small area.

   c. This is a low-pressure situation because weight is distributed over the large area of the ski surface.

3. 

4.

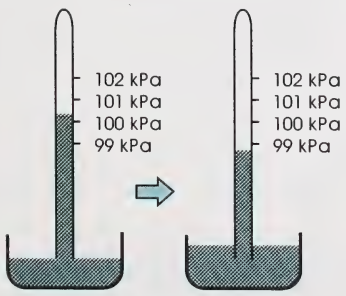
Location	Pressure
Calgary	**97 kPa**
Vancouver	**101 kPa**
Mt. Everest	**33 kPa**
High in an airplane	**27 kPa**

5. An average-sized person (about 65 kg) would exert 0.637 kPa of pressure if standing on a board 1 m × 1 m. (To convert from pounds, you first divide by 2.2 lb/kg; then proceed in the same way.)

$$65\text{ kg} = 65\text{ kg} \times \frac{9.8\text{ N}}{\text{kg}} = 637\text{ N} \qquad \text{pressure (kPa)} = 637\text{ N/m}^2 \times \frac{1\text{ kPa}}{1000\text{ N/m}^2} = 0.637\text{ kPa}$$

$$\text{pressure}\left(\frac{\text{N}}{\text{m}^2}\right) = \frac{637\text{ N}}{1\text{ m}^2} = \frac{637\text{ N}}{\text{m}^2}$$

6. a. At point A nothing pushes on the mercury. There is a vacuum in the top. At point B the atmosphere pushes on the mercury.

   b. 

7. The gas sample has the highest pressure.

8. You can tell that the gas sample has the highest pressure because it pushes the mercury down the farthest.

9. Since the gas sample exerts 9 kPa less pressure than the atmosphere, its pressure is 90 kPa.

10. a.

Condition	Temperature	Pressure
SATP	25°C	100 kPa
STP	0°C	101.3 kPa

b. Because an average room is about 25°C and 100 kPa is a common atmospheric pressure, SATP describes conditions most like those encountered in a normal room.

11. Here are some possible results.

Number of Books	Volume (mL)
0	40.0
1	31.7
2	25.5
3	21.0
4	18.2
5	15.9

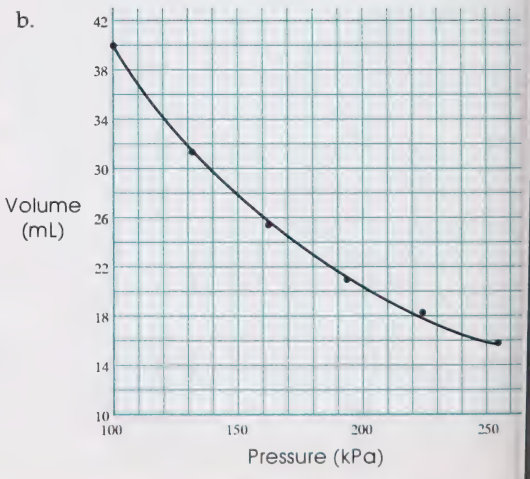
12. The volume decreased as the pressure increased.

13. The relationship between pressure and volume is indirect.

14. a. The following table shows a sample set of volume evidence.

Number of Books	Total Pressure (kPa)	Syringe Volume (mL)
0	100	40.0
1	131	**31.7**
2	162	**25.5**
3	193	**21.0**
4	224	**18.2**
5	255	**15.9**

b.



15. a. The sample values are written to three significant digits in the last column because each of the multiplied values had three significant digits.

p (kPa)	v (mL)	$p \times v$ (kPa • mL)
100	40.0	4.00×10^3
131	**31.7**	**4.15×10^3**
162	**25.5**	**4.13×10^3**
193	**21.0**	**4.05×10^3**
224	**18.2**	**4.08×10^3**
255	**15.9**	**4.05×10^3**

b. Within ± 4%, all the products are nearly the same or constant. This means that $p \times v$ = a constant.

16.

Mass on Scale (kg)	Syringe Volume (mL)
0	40.0
2	**29.7**
4	**23.0**
6	**19.0**
8	**15.8**
10	**13.8**

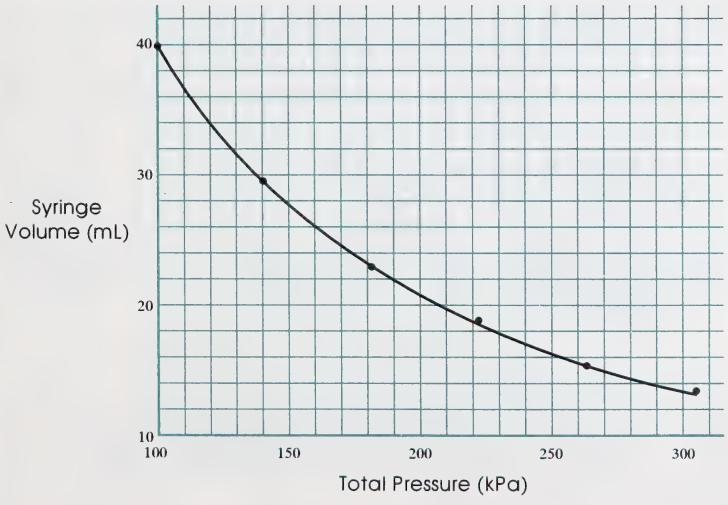
17. The volume decreased as the pressure increased.

18. The relationship between pressure and volume is indirect.

19.

Scale Mass (kg)	Total Pressure (kPa)	Syringe Volume (mL)
0	100	40.0
2	141	**29.7**
4	182	**23.0**
6	223	**19.0**
8	264	**15.8**
10	305	**13.8**

20.



21. a.

p (kPa)	v (mL)	$p \times v$ (kPa • mL)
100	40.0	4.00×10^3
141	**29.7**	**4.19×10^3**
182	**23.0**	**4.19×10^3**
223	**19.0**	**4.24×10^3**
264	**15.8**	**4.17×10^3**
305	**13.8**	**4.21×10^3**

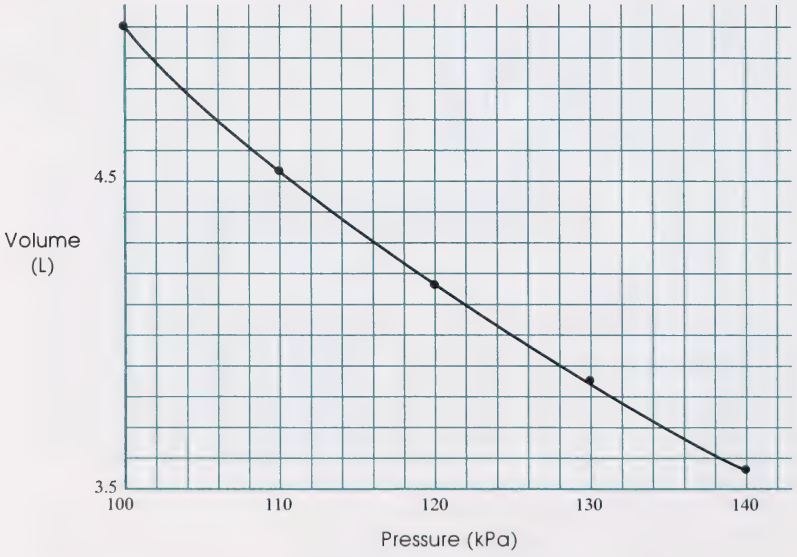
b. Within ± 2%, the product values are fairly close to each other; therefore, $p \times v$ = a constant.

22. The relationship between pressure and volume is indirect. As the pressure of a gas increases, its volume decreases such that $p \times v$ = a constant.

23. a. The mass of gas stays the same throughout either experiment.

b. The mass of gas is a controlled variable.

24.



25. The relationship between pressure and volume is indirect.

26. a.

Pressure (kPa)	Volume (L)	$p \times v$ (kPa • mL)
100	5.00	500
110	**4.55**	**500.5**
120	**4.16**	**499.2**
130	**3.85**	**500.5**
140	**3.57**	**499.8**

b. The products are almost identical numerically.

27. Yes. For any confined gas, $p \times v$ = the same number. As the pressure increases, the volume decreases.

28. Temperature and amount are controlled because they also have an effect on the volume of a gas. If they were allowed to change, you wouldn't know whether the pressure, temperature, or amount of gas was causing the observed changes in volume.

29. Boyle's law states that as the gas particles are forced closer together, they hit each other and the sides of the container more often, which increases the pressure.

30. Boyle's law in equation form is $p_1v_1 = p_2v_2$.

31. The inverse relationship of concentration was studied in Module 1. As the volume of water added to a solution increases, the concentration decreases **or** $C_1v_1 = C_2v_2$.

32. Textbook question 3:

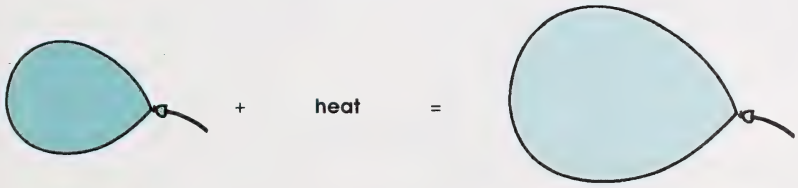
$p_1 = 100$ kPa $\quad p_2 = 250$ kPa
$v_1 = 600$ mL $\quad v_2 = ?$

$$p_1v_1 = p_2v_2$$
$$\frac{p_1v_1}{p_2} = v_2$$
$$\frac{100 \text{ kPa } (600 \text{ mL})}{250 \text{ kPa}} = v_2$$
$$240 \text{ mL} = v_2$$

The volume of air is 240 mL when the pressure increases to 250 kPa.

Section 2: Activity 3

1.



2. a. When heated air expands, it becomes less dense. This makes the hot air balloon rise.

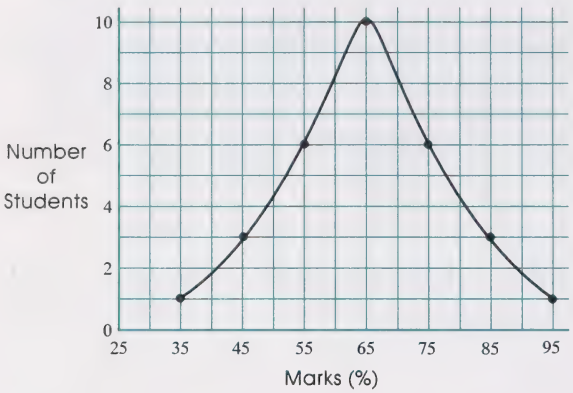
b. The higher the temperature you get, the more expansion of gases is produced causing a better, more forceful explosion.

c. When air is heated over the Earth, it rises. Vultures can soar in the rising air without having to expend energy by flapping their wings.

d. The gasoline in the cylinder of a car engine burns. The heat produced causes expansion of the gases produced. This helps to push the piston down in the cylinder and cause the car to move.

3. a. There are a large variety of kinetic energies in a gas sample.

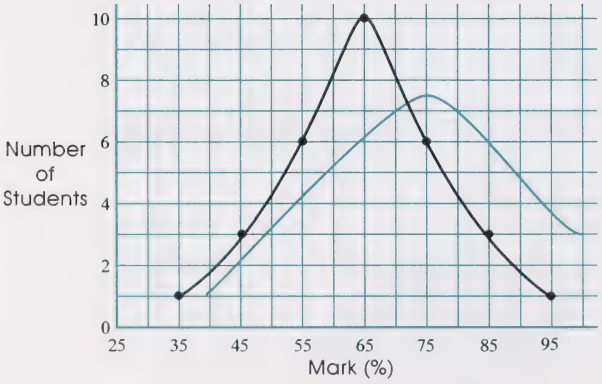
   b. A few particles in a cold air sample will have relatively high kinetic energies.

4. 

5. The shapes are very similar.

6. There are many possible marks in a classroom, and there are many possible kinetic energies in a gas sample.

7. The average mark of the class indicates the average performance of students in a classroom.

8. 

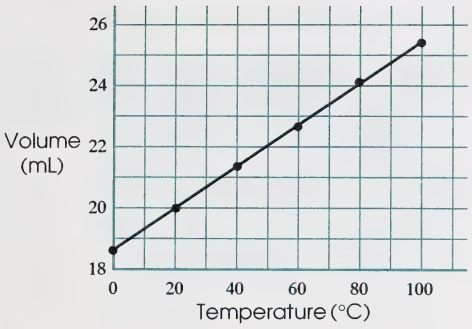
   The curve shows that the average for the class would be higher if the students studied harder.

9. Both curves show a shift to the right of the original curve.

10. Here are some possible values.

Temperature (°C)	Volume (mL)
0.0	**18.6**
Room temperature **20.0**	20.0
40.0	**21.4**
60.0	**22.7**
80.0	**24.1**
Boiling water **100.0**	**25.4**

11.



12. a. The volume increases as the temperature of a gas increases.

b. There is a direct relationship between temperature and volume as both variables increase together.

13.

Temperature (°C)	Volume (mL)	$\frac{v}{T}\left(\frac{mL}{°C}\right)$
Room temperature – 20.0	20.0	1.00
40.0	**21.4**	**0.54**
60.0	**22.7**	**0.38**
80.0	**24.1**	**0.30**
Boiling water 100.0	**25.4**	**0.25**

14. There is no obvious relationship between the values of $\frac{v}{T}$ because the values are very different from each other.

15. Degrees Celsius can be converted to kelvin by adding 273 to the Celsius value. An example showing the conversion of 0°C to K is given.

$$0°C + 273 = 273\ K$$

Another example of the conversion of 215°C to kelvin is given.

$$215°C + 273 = 488\ K$$

16.

Unit	°C	K
Standard ambient temperature	**25**	**298**
Freezing point of water	**0**	**273**
Coldest temperature possible	**-273**	**0**
Body temperature	37	**310**

17. Illustration A best represents the comparison of sizes. Each degree is the same size in both scales.

18. a.

Temperature (°C)	Temperature (K)
0.0	273.0
20.0	**293.0**
40.0	**313.0**
60.0	**333.0**
80.0	**353.0**
100.0	**373.0**

b.

Temperature (K)	Volume (mL)	$\frac{v}{T}$ (mL) (K)
273.0	18.6	0.0681
293.0	**20.0**	**0.0683**
313.0	**21.4**	**0.0684**
333.0	**22.7**	**0.0682**
353.0	**24.1**	**0.0683**
373.0	**25.4**	**0.0681**

19. Yes, $\frac{v}{T}$ is a constant number when temperature is measured in kelvin. The ratio always gives about 0.068 (within about ± 0.3%).

20. Charles' law of gases states that for a combined gas sample, $\frac{v}{T\,(\text{K})}$ will always give a constant or $\frac{v_1}{T_1} = \frac{v_2}{T_2}$.

21. Pressure and the amount of gas must be controlled because they influence the volume of a gas as well.

22. Textbook question 1:

$v_1 = 0.10\ \text{L} \qquad v_2 = ?$
$T_1 = 298\ \text{K} \qquad T_2 = 371\ \text{K}$

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$
$$\frac{0.10\ \text{L}}{298\ \text{K}} = \frac{v_2}{371\ \text{K}}$$

$$\boxed{\frac{v_2}{371\ \text{K}} = \frac{0.10\ \text{L}}{298\ \text{K}}}$$

(The boxed step is shown here so you can understand how v_2 was moved to the left-hand side.)

$$v_2 = \frac{0.10\ \text{L}\ (371\ \text{K})}{298\ \text{K}}$$
$v_2 = 0.12\ \text{L}$ The final volume of carbon dioxide is 0.12 L.

23. a. ↓ temperature
b. ↓ pressure
c. ↑ temperature
d. ↑ pressure

24. Charles' law explains why baked goods are light and fluffy; the gas produced in pastry expands on heating to form bubbles.

25. As the gas molecules are heated, they move faster and their collisions exert more pressure on their container.

26. Textbook question 10:

a. As molecules gain kinetic energy, they move faster. This makes the force with which they hit the walls of the container greater. The pressure then increases.

b. When volume decreases, the particles are pushed closer together so that they hit each other and the walls of the container more often. This increases pressure.

c. Molecules of perfume travel through spaces between air molecules to rapidly spread through a room.

d. The pathway of a molecule in air is obstructed by the oxygen, nitrogen, and other molecules in the air. The perfume molecules take a random pathway.

27. Textbook question 4:

The volume of the balloon is 5.84 L.

$p_1 = 100$ kPa $\qquad p_2 = 90$ kPa

$v_1 = 5.00$ L $\qquad v_2 = ?$

$T_1 = 20°C\ (293\ K)$ $\qquad T_2 = 35°C\ (308\ K)$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

$$\frac{100\ \text{kPa}\ (5.00\ \text{L})}{293\ \text{K}} = \frac{90\ \text{kPa}\ (v_2)}{308\ \text{K}}$$

$$v_2 = \frac{100\ \text{kPa}\ (5.00\ \text{L})\ 308\ \text{K}}{293\ \text{K}\ (90\ \text{kPa})}$$

$$= 5.8\ \text{L}$$

Textbook question 5:

The valve opens at 240°C.

$p_1 = 150$ kPa $\qquad p_2 = 250$ kPa

$T_1 = 35°C\ (308\ K)$ $\qquad T_2 = ?$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2},\ v_1 = v_2$$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\frac{150\ \text{kPa}}{308\ \text{K}} = \frac{250\ \text{kPa}}{T_2}$$

$$T_2 = \frac{308\ \text{K}\ (250\ \text{kPa})}{150\ \text{kPa}}$$

$$= 513\ \text{K}\ (240°C)$$

Textbook question 7:

The volume of gas that can be obtained from the cylinder is 7.9 L.

$p_1 = 800$ kPa $\qquad p_2 = 100$ kPa

$v_1 = 1.0$ L $\qquad v_2 = ?$

$T_1 = 30°C\ (303\ K)$ $\qquad T_2 = 25°C\ (298\ K)$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

$$\frac{800\ \text{kPa}\ (1.0\ \text{L})}{303\ \text{K}} = \frac{100\ \text{kPa}\ (v_2)}{298\ \text{K}}$$

$$v_2 = \frac{800\ \text{kPa}\ (1.0\ \text{L})\ 298\ \text{K}}{303\ \text{K}\ (100\ \text{kPa})}$$

$$= 7.9\ \text{L}$$

28. Textbook question 1:

a. Boyle's law – The volume of a gas sample will decrease as pressure is increased.

b. Charles' law – The volume of a gas will increase as temperature increases.

c. the law of combining volumes – The volume of a gas varies directly with temperature and inversely with pressure.

Textbook question 14:

Two kinds of weather systems are high-pressure systems and low-pressure systems.

Textbook question 16:

The new volume is 8.23 L.

$p_1 = 100 \text{ kPa}$ $\quad p_2 = 350 \text{ kPa}$

$v_1 = 28.8 \text{ L}$ $\quad v_2 = ?$

$$p_1v_1 = p_2v_2$$

$$100 \text{ kPa } (28.8 \text{ L}) = 350 \text{ kPa } (v_2)$$

$$v_2 = \frac{100 \text{ kPa } (28.8 \text{ L})}{350 \text{ kPa}}$$

$$= 8.23 \text{ L}$$

Textbook question 17:

The final pressure of steam is 302 kPa.

$p_1 = 600 \text{ kPa}$ $\quad p_2 = ?$

$v_1 = 10.0 \text{ kL}$ $\quad v_2 = 18.0 \text{ kL}$

$T_1 = 150°\text{C } (423 \text{ K})$ $\quad T_2 = 110°\text{C } (383 \text{ K})$

$$\frac{p_1v_1}{T_1} = \frac{p_2v_2}{T_2}$$

$$\frac{600 \text{ kPa } (10.0 \text{ kL})}{423 \text{ K}} = \frac{p_2 \ (18.0 \text{ kL})}{383 \text{ K}}$$

$$p_2 = \frac{600 \text{ kPa } (10.0 \text{ kL}) \ 383 \text{ K}}{423 \text{ K } (18.0 \text{ kL})}$$

$$= 302 \text{ kPa}$$

Section 2: Activity 4

1. a. $N_{2(g)}$, $O_{2(g)}$, $CO_{2(g)}$, $H_2O_{(g)}$

b. $He_{(g)}$

c. $N_{2(g)}$, $O_{2(g)}$, $CO_{2(g)}$, $H_2O_{(g)}$

d. $CO_{2(g)}$

2. Because the volume of gases can be expanded or reduced, which means that there must be spaces between the molecules, Dalton's idea that gas molecules pack close together can be refuted.

3. a. The space between gas particles is more important than the size of the particles in determining the amount of gas that will fit in a container.

b. The space between gas particles can be affected by pressure, temperature, or the amount of gas.

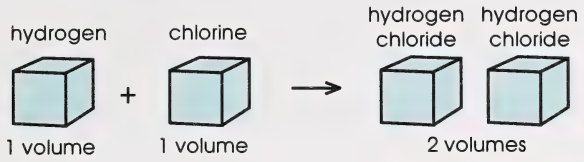
4. a. iii b. i c. ii

5. Both have the same **number of gas particles** at the same **pressure**, **temperature**, and **volume**.

6. a. iii b. ii c. i

7. hydrogen + chlorine → hydrogen chloride
   1 volume 1 volume 2 volumes

   or



8. a. **2** volume(s) hydrogen + **1** volume(s) oxygen → **2** volume(s) water

   b. **3** volume(s) hydrogen + **1** volume(s) nitrogen → **2** volume(s) ammonia

9. a. $2\ H_{2(g)} + 1\ O_{2(g)} \rightarrow 2\ H_2O_{(g)}$ c. $3\ H_{2(g)} + 1\ N_{2(g)} \rightarrow 2\ NH_{3(g)}$

   b. $1\ H_{2(g)} + 1\ Cl_{2(g)} \rightarrow 2\ HCl_{(g)}$

10. The volumes are the same as the coefficients.

11. The law of combining volumes states that gases tend to react in simple whole-number ratios.

12. Dalton would have simply added the volumes together since the molecules, according to him, were close together anyway.

Reaction	Gay-Lussac's Determination	Dalton's Prediction
1 L N_2 + 3 L H_2 →	2 L NH_3	**4** L NH_3
1 L H_2 + 1 L Cl_2 →	2 L HCl	**2** L HCl
2 L H_2 + 1 L O_2 →	2 L H_2O	**3** L H_2O

13. a. You can't just create matter (conservation of matter) to make substances balance in equations.

    b. The product cannot be a double burger (or take the space of a double particle); the product must still be a single particle. The rule is as follows: single particle – single volume.

    c. You can't split patties or atoms in normal chemical reactions.

14. Avogadro's hypothesis states that equal volumes of gases contain equal numbers of particles at the same pressure and temperatures.

15. Avogadro introduced the concept that elements can exist as molecules (combinations of atoms) rather than just single atoms.

16. The number of molecules present and the volume of each gas present are the same.

17. The search for the smallest gas particle ended with the molecule. This is true for almost all reacting gases.

18. Under the same conditions of temperature and pressure, SO_3 will take up the same volume as SO_2 because there are the same number of particles.

$$\begin{array}{lllll} 2\,SO_{2(g)} & + & O_{2(g)} & \rightarrow & 2\,SO_{3(g)} \\ 20\ L & & 10\ L & & 20\ L \end{array}$$

19. No, there is not really a secret formula gas that gives more volume per molecule. All gases take up the same volume per molecule.

20. Textbook question 19:

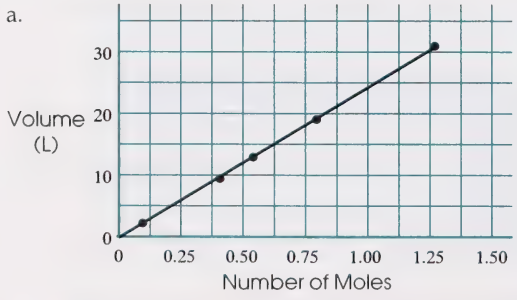
    a. The ratio is 1:2 for each product. Six volumes of oxygen go to twelve volumes of CO_2 and twelve volumes of H_2O.

    b. The second reaction will produce the greater degree of leavening because four volumes come from zero volumes (the $C_6H_{12}O_6$ is a solid), which is a huge ratio.

21. Some examples of theories that were not immediately accepted are Mendeleyev's periodic table, Mendel's theory of genes, and Copernicus' model of the solar system.

22. Statements **a.** and **c.** explain why Avogadro's theory was not immediately accepted.

23. a.



    b. The relationship between moles of gas and volume is direct as both moles and volume increase together.

24. a.

Moles (mol)	Volume (L)	$\frac{v}{n}\left(\frac{L}{mol}\right)$
0.12	2.9	**24**
0.38	9.4	**25**
0.56	13.9	**25**
0.78	19.3	**25**
1.26	31.2	**25**

    b. Avogadro's law is $\frac{v}{n}$ = a constant. Therefore, for a sample of gas where pressure and temperature are controlled, $\frac{v_1}{n_1} = \frac{v_2}{n_2}$.

25. Pressure and temperature need to be controlled when using Avogadro's law to solve problems because they also affect the volume of a gas.

26. The number of moles that will fill up 7.6 L is 2.5 mol.

$v_1 = 35.8\ \text{L}$ $\qquad$ $v_2 = 7.6\ \text{L}$

$n_1 = 11.6\ \text{mol}$ $\qquad$ $n_2 = ?$

$$\frac{v_1}{n_1} = \frac{v_2}{n_2}$$

$$\frac{35.8\ \text{L}}{11.6\ \text{mol}} = \frac{7.6\ \text{L}}{n_2}$$

$$n_2 = \frac{7.6\ \text{L}\ (11.6\ \text{mol})}{35.8\ \text{L}}$$

$$= 2.5\ \text{mol}$$

Section 2: Activity 5

1. Textbook question 31:

   Boyle's law can be verified by attaching the bicycle pump to the pressure gauge and then recording pressure from the pressure gauge as the volume of gas in the pump is varied.

   Avogadro's law can be verified by using the pump and a balloon. The pump injects the same mass of air with each pump of the handle. Therefore, it also injects the same number of moles. One could add air to the balloon one pump at a time, each time measuring the volume of the balloon by water displacement in a pail.

2. For Boyle's law you would multiply the pressure from the gauge by the volume in the pump for each measurement and then compare the products. The products should be similar.

   For Avogadro's law you would divide the volume of the balloon by the number of pumps and then compare the answers. The answers should be similar.

3. A balloon will be submerged in water of varying temperatures. At each temperature the volume of the balloon will be calculated by water displacement.

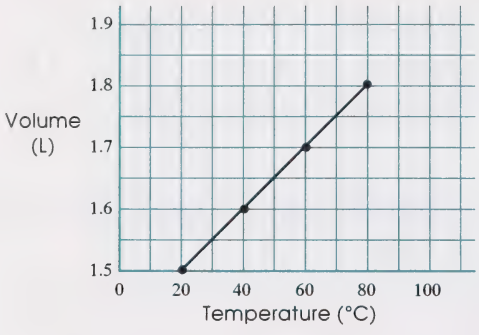
4. Following is a list of the steps in the procedure.

   - Half fill a pail with cold water.
   - Submerge a three-quarter-filled balloon into the water using a plate to hold it under so that your hands don't go into the water.
   - Mark the level of the water after allowing a few minutes for the air in the balloon to reach the water temperature.
   - Measure the water temperature and record it in the data table.
   - Take out the balloon and mark the water level. Use a measuring cup to measure the volume between the two marked levels. Record.
   - Repeat the procedure three more times increasing the water temperature each time with hot water. Try for 20°C, 40°C, 60°C, and 80°C water. Caution: Don't burn yourself.

5. Your evidence will vary because it depends on the initial volume of the balloon. A sample is given here.

Temperature (°C)	Volume of Water Displaced by Balloon	Volume of Balloon
20	1.50 L	1.50 L
40	1.60 L	1.60 L
60	1.70 L	1.70 L
80	1.80 L	1.80 L

6.



7. The calculation required is $\frac{v\,(\mathrm{L})}{T\,(\mathrm{K})}$. Values of $\frac{v}{T}$ for supplied data are as follows:

$\frac{v}{T} = \frac{1.50\ \mathrm{L}}{293\ \mathrm{K}} = 0.0051$ $\qquad$ $\frac{v}{T} = \frac{1.70\ \mathrm{L}}{333\ \mathrm{K}} = 0.0051$

$\frac{v}{T} = \frac{1.60\ \mathrm{L}}{313\ \mathrm{K}} = 0.0051$ $\qquad$ $\frac{v}{T} = \frac{1.80\ \mathrm{L}}{353\ \mathrm{K}} = 0.0051$

The value of $\frac{v}{T}$ is constant.

8. a. It is difficult to get accurate values for volume in a pail. Hotter temperatures make it difficult to hold the balloon under water completely.

   b. A more accurate device with a measurement scale would minimize the error.

9. Textbook question 5:

   A law is a statement of regularity based on empirical data. For example, Charles' law, indirectly relating pressure to volume, is based on pressure-volume measurements. A theory is a statement (or statements) that attempts to explain why empirical regularities occur and can be used to predict future empirical data. The kinetic molecular theory explains the behaviour of gases and can be used to predict outcomes of experiments that test the KMT.

   Textbook question 6:

   Avogadro's idea is theoretical. No one can see that equal volumes of gases have equal numbers of particles. This is an idea that explains many empirical phenomena, but has yet to be proven.

Section 2: Activity 6

1. The volume, temperature, number of moles, and pressure completely describe a confined gas sample.

2. a. The ideal gas law in equation form is $pv = nRT$.

   b. R is the universal gas constant. It is equal to $8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$.

3. Since $pv = nRT$, $v = \frac{nRT}{p}$

$$= \frac{1.00 \text{ mol} \left(8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 298 \text{ K}}{100 \text{ kPa}}$$

$= 24.8$ L The volume of one mole of a gas under SATP is 24.8 L.

4. $p_1 v_1 = n_1 R T_1$ $p_2 v_2 = n_2 R T_2$

Pressure is controlled so $p_1 = p_2$

$p_1 = \frac{n_1 R T_1}{v_1}$ $p_2 = \frac{n_2 R T_2}{v_2}$

$$\frac{n_1 R T_1}{v_1} = \frac{n_2 R T_2}{v_2}$$

$n_1 = n_2$ so that $\frac{R T_1}{v_1} = \frac{R T_2}{v_2}$, and

R is the constant so $\frac{T_1}{v_1} = \frac{T_2}{v_2}$

and $\frac{v_1}{T_1} = \frac{v_2}{T_2}$ Charles' Law.

5. Textbook question 24:

The amount of methane gas present is 0.0410 mol.

$p = 210$ kPa $R = 8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = 500$ mL (0.500 L) $T = 35°\text{C}$ (308 K)

$n = ?$

$pv = nRT$

$n = \frac{pv}{RT}$

$$= \frac{210 \text{ kPa } (0.500 \text{ L})}{8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}} (308 \text{ K})}$$

$= 0.0410$ mol of methane

Textbook question 25:

The pressure is 1.6×10^3 kPa.

$p = ?$ $R = 8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = 50$ L $T = 40°\text{C}$ (313 K)

$n = 30$ mol

$pv = nRT$

$p = \frac{nRT}{v}$

$$= \frac{30 \text{ mol} \left(8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 313 \text{ K}}{50 \text{ L}}$$

$= 1.6 \times 10^3$ kPa

6. Textbook question 10:

a. The amount is 0.21 mol.

$p = 100 \text{ kPa}$ $\quad R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = 5.1 \text{ L}$ $\quad T = 25°\text{C} \ (298 \text{ K})$

$n = ?$

$$n = \frac{pv}{RT}$$

$$= \frac{100 \text{ kPa} \ (5.1 \text{ L})}{8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}} \ (298 \text{ K})}$$

$$= 0.21 \text{ mol}$$

b. The amount is 9.24×10^{-4} mol.

$p = 101.3 \text{ kPa}$ $\quad R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = 20.7 \text{ mL} \ (0.0207 \text{ L})$ $\quad T = 0°\text{C} \ (273 \text{ K})$

$n = ?$

$$n = \frac{pv}{RT}$$

$$= \frac{101.3 \text{ kPa} \ (0.0207 \text{ L})}{8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}} \ (273 \text{ K})}$$

$$= 0.000924 \text{ mol}$$

$$= 9.24 \times 10^{-4} \text{ mol}$$

c. The amount is 3.6×10^{3} mol.

$p = 100 \text{ kPa}$ $\quad R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = 90 \text{ kL} \left(9.0 \times 10^{4} \text{ L}\right)$ $\quad T = 25°\text{C} \ (298 \text{ K})$

$n = ?$

$$n = \frac{pv}{RT}$$

$$= \frac{100 \text{ kPa} \left(9.0 \times 10^{4} \text{ L}\right)}{8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}} \ (298 \text{ K})}$$

$$= 3.6 \times 10^{3} \text{ mol}$$

Textbook question 11:

a. The volume is 1.24×10^{4} L.

$p = 100 \text{ kPa}$ $\quad R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = ?$ $\quad T = 25°\text{C} \ (298 \text{ K})$

$n = 500 \text{ mol}$

$$v = \frac{nRT}{p}$$

$$= \frac{500 \text{ mol} \left(8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 298 \text{ K}}{100 \text{ kPa}}$$

$$= 1.24 \times 10^{4} \text{ L}$$

b. The volume is 1.4×10^{6} L.

$p = 100 \text{ kPa}$ $\quad R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$

$v = ?$ $\quad T = 25°\text{C} \ (298 \text{ K})$

$n = 56 \text{ kmol} \left(5.6 \times 10^{4} \text{ mol}\right)$

$$v = \frac{nRT}{p}$$

$$= \frac{5.6 \times 10^{4} \text{ mol} \left(8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 298 \text{ K}}{100 \text{ kPa}}$$

$$= 1.4 \times 10^{6} \text{ L}$$

7. There are 121 g of CO_2 in 2.76 mol of CO_2.

$m = ?$

$n = 2.76 \text{ mol } CO_2$

$M = \dfrac{44.01 \text{ g}}{\text{mol}}$

$m_{(CO_2)} = 2.76 \cancel{\text{ mol } CO_2} \times \dfrac{44.01 \text{ g}}{\cancel{\text{mol } CO_2}}$ by factor labelling, or $m = nM$

$= 121 \text{ g}$

$= 2.76 \text{ mol} \left(\dfrac{44.01 \text{ g}}{\text{mol}} \right)$

$= 121 \text{ g}$

8. Textbook question 28:

The following formula can be used to calculate molar mass of a gas:

$pv = nRT$

Since $n = \dfrac{m}{M}$,

$pv = \dfrac{m}{M} RT$

$pvM = mRT$

$M = \dfrac{mRT}{pv}$

= molar mass

Textbook question 29:

The molar mass is 28.4 g/mol.

$m = 1.25 \text{ g}$ $\quad p = 100 \text{ kPa}$

$R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$ $\quad v = 1.00 \text{ L}$

$T = 0°\text{C} \ (273 \text{ K})$ $\quad M = ?$

$M = \dfrac{mRT}{pv}$

$= \dfrac{1.25 \left(8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}} \right) 273 \text{ K}}{100 \text{ kPa} \ (1.00 \text{ L})}$

$= 28.4 \text{ g/mol}$

9. The following four characteristics of an ideal gas were listed in Activity 1:

- Particles have no volume.
- Particles have no attraction or repulsion for each other.
- Particles move in straight lines unless they collide with each other or the sides of a container.
- Collisions of gas particles are perfectly elastic.

10. Low temperatures and high pressures cause the gas particles to get closer together which makes them behave in a non-ideal way.

11. Statements **a.** and **c.** illustrate non-ideal behaviour of real gases.

12. a. Gas 1 represents **ideal** gas behaviour.

(For an ideal gas, $p \times v$ should be constant.)

Gas 2 represents **real** gas behaviour.

b. Gas 1 represents **real** gas behaviour.

Gas 2 represents **ideal** gas behaviour.

13. Possible results are shown:

Mass (g)	T (°C)	T (K)	p (kPa)	v (mL)
1.49 g	23 °C	296 K	98.2 kPa	632 mL

14. Copy the table from the preceding question (question 13, Section 2, Activity 6).

15. The molar mass of butane is 59.1 g/mol.

$$M = \frac{mRT}{pv}$$

$$= \frac{1.49\ \text{g}\left(8.314\ \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 296\ \text{K}}{98.2\ \text{kPa}\ (0.632\ \text{L})}$$

$$= 59.1\ \text{g/mol}$$

16. If the levels are the same, then the pressure exerted by the butane (B) is equal to that exerted by the atmosphere (A). You can then use atmospheric pressure for the pressure of the butane.

17. a. The difference in the example is 1.0 g/mol.

    b. No, you could not justify a molar mass answer to two decimal places because the equipment used only allowed for one-decimal-place precision at the most.

18. The largest source of error may be the drying of the lighter. So, if it was left to stand for a few days, the result may be better.

19. Methane is used for

- a fuel for some barbecues
- heating houses in cities and towns
- heating water in hot water tanks

Propane is used for

- a fuel in certain vehicles (e.g., buses)
- a barbecue fuel
- heating some houses in rural areas

20. Hydrogen has such a low boiling point that it would be very difficult to get it to exist as a liquid.

21. Hydrogen is used as a fuel on the shuttle because it has a high ratio of energy to mass, 141 kJ/g, which makes it very efficient.

22. Methane and propane are not fuels of the future because they will only last a few dozen more years, and they are nonrenewable resources.

23. c. It gives off only H_2O.

24. Because hydrogen is a leaky gas, it is expensive to make. It is wasteful to let it leak and drift away. Also, it is explosive and if it leaks, the situation is dangerous.

25. a. iii b. i c. iv d. ii

26.

Pros of Using H_2 Fuel	Cons of Using H_2 Fuel
• environmentally friendly • plenty of water around to make it • new breakthroughs making it cheaper	• leaky • explosive • currently expensive • low density

27. Textbook question 3:

The ideal gas law states that the pressure of a gas times its volume equals the products of the moles of gas, the gas constant, and the temperature in Kelvin degrees: $pv = nRT$. The volume of a gas is affected directly by temperature and the number of moles, but indirectly by pressure.

Textbook question 4:

Under conditions of high temperature and low pressure, a real gas behaves more ideally.

Textbook question 15:

a. When the gas pressure doubles, the new volume of a sample of carbon dioxide gas is 150 L.

$$v_1 = 300 \text{ L}$$
$$2\,p_1 = p_2$$
$$v_2 = ?$$

$$p_1 v_1 = p_2 v_2$$
$$p_1 (300 \text{ L}) = 2\,p_1 v_2$$
$$v_2 = \frac{\cancel{p_1} \times 300 \text{ L}}{2\cancel{p_1}}$$
$$= 150 \text{ L}$$

b. When the temperature increases, the new volume is 330 L.

$$v_1 = 300 \text{ L} \qquad v_2 = ?$$
$$T_1 = 30°\text{C} \ (303 \text{ K}) \qquad T_2 = 60°\text{C} \ (333 \text{ K})$$

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$
$$\frac{300 \text{ L}}{303 \text{ K}} = \frac{v_2}{333 \text{ K}}$$
$$v_2 = \frac{300 \text{ L} \ (333 \text{ K})}{303 \text{ K}}$$
$$= 330 \text{ L}$$

c. The molar volume of carbon dioxide gas at 22°C and 94.0 kPa is 26.1 L.

$$p = 94.0 \text{ kPa} \qquad R = 8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$$
$$v = ? \qquad T = 22°\text{C} \ (295 \text{ K})$$
$$n = 1.00 \text{ mol}$$
$$pv = nRT$$
$$v = \frac{nRT}{p}$$
$$= \frac{1.00 \text{ mol} \left(8.314 \frac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}} \right) 295 \text{ K}}{94.0 \text{ kPa}}$$
$$= 26.1 \text{ L}$$

Textbook question 22:

The volume of chlorine gas is 1.70×10^5 L.

$p = 400$ kPa
$v = ?$
$n = 26.5$ kmol
$= 2.65 \times 10^4$ mol
$R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$
$T = 35°\text{C}\ (308\ \text{K})$

$$pv = nRT$$

$$v = \frac{nRT}{p}$$

$$= \frac{2.65 \times 10^4\ \text{mol}\left(8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 308\ \text{K}}{400\ \text{kPa}}$$

$$= 1.70 \times 10^5\ \text{L}$$

Textbook question 23:

The amount of bromine present is 0.33 mol.

$p = 60$ kPa
$v = 18.8$ L
$n = ?$
$R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$
$T = 140°\text{C}\ (413\ \text{K})$

$$pv = nRT$$

$$n = \frac{pv}{RT}$$

$$= \frac{60\ \text{kPa}\ (18.8\ \text{L})}{8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\ (413\ \text{K})}$$

$= 0.33$ moles $Br_{2(g)}$

Textbook question 24:

$m = 9.31\ \text{g} - 7.02\ \text{g}$
$R = 8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}$
$T = 23.4°\text{C}\ (296.4\ \text{K})$
$p = 102.2$ kPa
$v = 1.25$ L
$M = ?$

a. The molar mass of this common gas is 44.2 g/mol.

$$M = \frac{mRT}{pv}$$

$$= \frac{(9.31\ \text{g} - 7.02\ \text{g})\left(8.314 \dfrac{\text{kPa} \bullet \text{L}}{\text{mol} \bullet \text{K}}\right) 296.4\ \text{K}}{102.2\ \text{kPa}\ (1.25\ \text{L})}$$

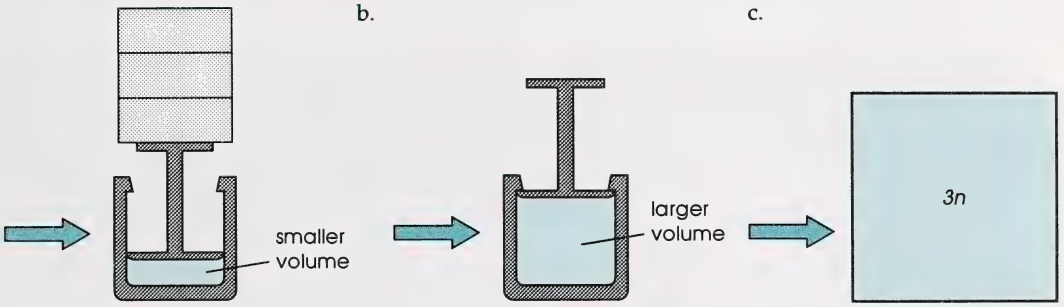
$= 44.2$ g/mol

b. This could be CO_2, as it has a molar mass very close to 44.2 g/mol (44.01 g/mol). However, this can't be certain because other gases have molar masses close to this value.

Section 2: Follow-up Activities

Extra Help

1. a. b. c.



2. a. ii b. iii c. i

3.

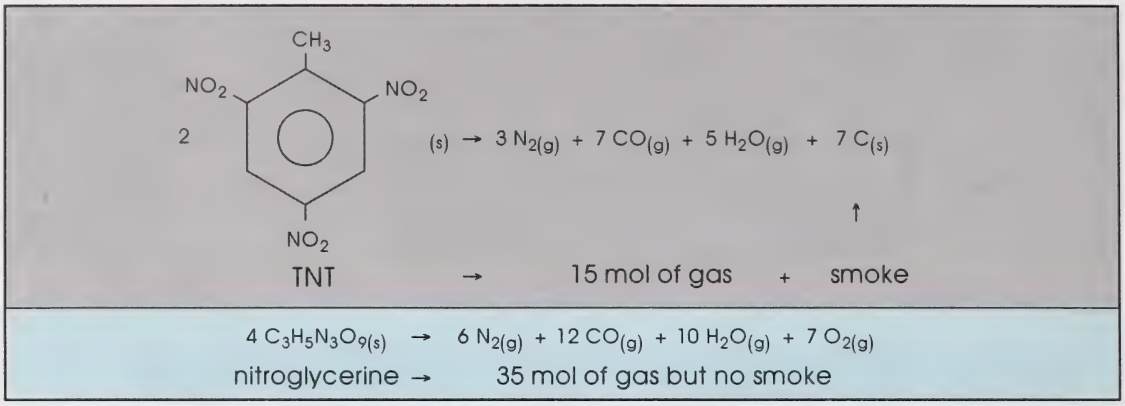
Law/Theory	Scientist	Variable	Effect on a Volume of Gas if Variable Is Decreased
$p_1v_1 = p_2v_2$	**Boyle**	pressure	**volume ↑**
$\frac{v_1}{T_1} = \frac{v_2}{T_2}$	**Charles**	temperature	**volume ↓**
$\frac{v_1}{n_1} = \frac{v_2}{n_2}$	**Avogadro**	number of moles	**volume ↓**

4.

Problem →			**Solution**
Variable(s) Given (Known)	Variable(s) Changed	Solve for	Law/Theory Used to Solve
p, *v*	*v*	*p*	**Boyle's law**
v, *T*	*T*	*v*	**Charles' law**
p, *T*, *v*	*p*, *T*	*v*	**combined gas law**
p, *T*, *v*, *n*	*p*, *T*, *v*	*n*	**ideal gas law**
v, *n*	*v*	*n*	**Avogadro's theory**
p, *T*, *v*	*p* (with *v* controlled)	*T*	**Charles' law**
p, *T*, *v*, *n*	*p*, *T* (with *n* controlled)	*v*	**combined gas law**

Enrichment

1. The shock wave from an explosion depends on the very fast expansion of a lot of gas. Explosions create gases as they react, and the gases are heated to expand even more. Here are the reactions of TNT and nitroglycerine.



Dynamite is a mixture of nitroglycerine, ammonium nitrate, sodium nitrate, and wood pulp. This mixture makes dynamite fairly safe.

2. You don't have to go very deep (less than 0.5 m) in the water before the pressure is so high that your muscles aren't strong enough to bring air into your lungs. Scuba diving equipment supplies air at a pressure high enough to overcome the pressure of the water on your chest. The high pressure of the gases in the tank can have a dangerous affect on the diver. Oxygen at too high a pressure is toxic. Babies exposed to pure oxygen at birth can have their sight irreversibly damaged. Nitrogen is also dangerous. At high pressures, nitrogen dissolves in the blood. When a diver surfaces, bubbles of nitrogen form in the blood. Depending upon when these bubbles form, severe pain can result – or even death. The pain results from the nitrogen bubbles collecting at various bends in the blood vessels, due to things like joints in the body – hence the term "bends". The bubbles create pressure on the vessel walls which causes the pain. Nitrogen also has a narcotic effect in the blood. It can make a diver behave as though drunk.

3. Gases at the same temperature have the same average kinetic energy. Since kinetic energy = mv^2, where m = mass and v = velocity, particles of differing mass have different velocities if their kinetic energy is the same. Small gas particles like helium and hydrogen have the largest velocities at a given kinetic energy. This enables them to diffuse through small holes (effusion) more quickly than larger gas particles. This is why helium balloons deflate so much quicker than air-filled balloons.

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Chemistry 20

Student Module Booklet

Module 2

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